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Cost-Benefit Analysis of Mexico's Heavy-duty Emission Standards (NOM 044)

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Executive Summary

Mexico is planning to revise its existing emissions standards for diesel heavy-duty vehicles (HDVs). The existing regulation, Norma Oficial Mexicana 044 (NOM 044), requires new vehicles to meet either U.S. Environmental Protection Agency (EPA) 2004 or Euro IV standards. Revisions to NOM 044 standards will require manufacturers of new heavy-duty vehicles to move directly to either EPA 2010 or Euro VI standards, skipping over any interim steps. The implementation of these vehicle standards will be coordinated with the nationwide availability of ultralow-sulfur diesel (ULSD) with fewer than 15 parts per million (ppm) sulfur, which is anticipated to be achieved under a separate regulation by October 2017. The purpose of this paper is to report on the results, methods, and underlying assumptions of a cost-benefit analysis that the ICCT conducted to support the decision-making process for updating NOM 044. The results of this analysis, as well as other technical considerations (e.g., equivalency of EPA 2010 and Euro VI standards) are summarized in the ICCT working paper *Revising Mexico's NOM 044 standards: Considerations for decision-making* (Blumberg et al., 2014).

International context of heavy-duty emission standards

Current NOM 044 standards, last updated in 2006, fall behind eight of the top vehicle markets, five of which have adopted world-class standards equivalent to EPA 2010 or Euro VI for HDVs (TransportPolicy.net, 2014). EPA 2010 and Euro VI are functionally equivalent standards, which take advantage of commercially available and cost-effective technologies capable of reducing emissions of particulate matter (PM) up to 98 percent and oxides of nitrogen (NO_x) by 89-96 percent below EPA 2004 levels (EPA, 2010a). As shown in Figure 1, the European Union, the U.S., Canada, Japan, and South Korea have adopted Euro VI or equivalent standards for HDVs.

Benefits and costs of the proposed standard

This analysis makes several simplifying assumptions regarding the timing and phase in of cleaner fuels and vehicles, taking into account only the new vehicles added to the fleet and the fuel used in those vehicles. In the baseline these vehicles are EPA 2004 vehicles supplied with 500 ppm sulfur fuel. Under the NOM 044 scenario, starting in 2018 all new vehicles are assumed to be EPA 2010 vehicles supplied with 15 ppm sulfur fuel. This analysis does not consider the benefits or costs of improved fuel quality for use in the existing vehicle fleet.

This study demonstrates that updating NOM 044 emission standards to match EPA 2010 or Euro VI requirements is a highly cost-effective means of reducing the environmental impacts of diesel heavy-duty vehicles in Mexico. Among the key findings:

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ABOUT THIS SERIES ICCT's Heavy-Duty Vehicle Policies for Mexico series is intended to provide technical inputs in support of Mexico's development of transportation and environmental policies to reduce pollutant emissions, fuel consumption, and health and environmental impacts of heavy-duty vehicles. Publications in the series include global comparative reviews, technical studies, and cost-benefit analyses.

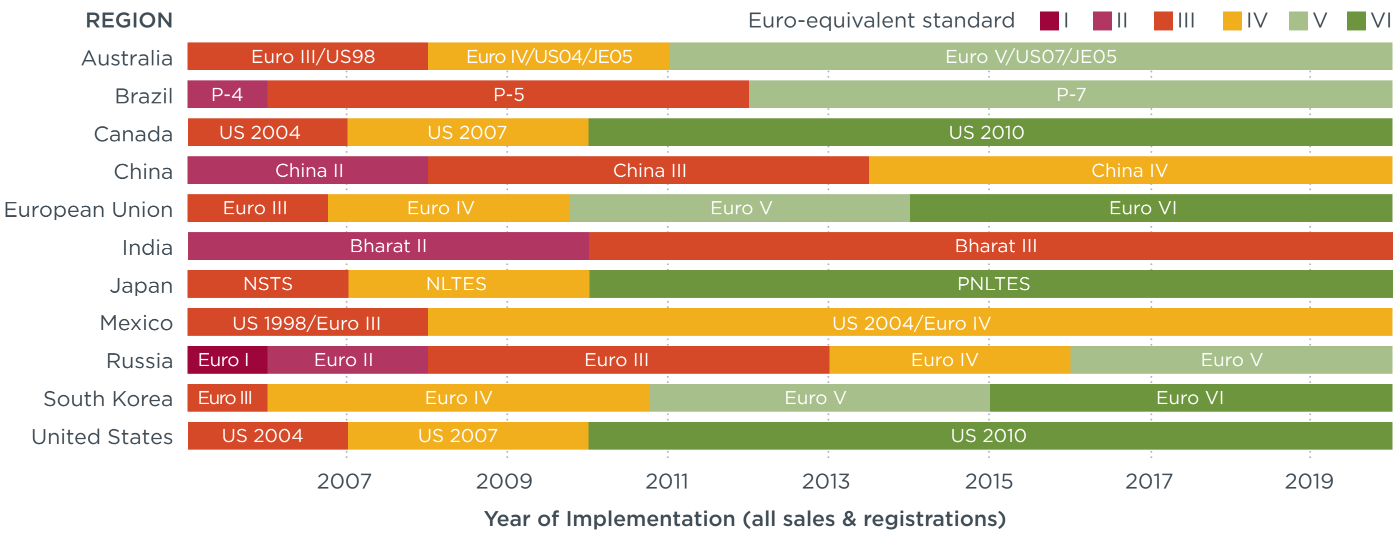
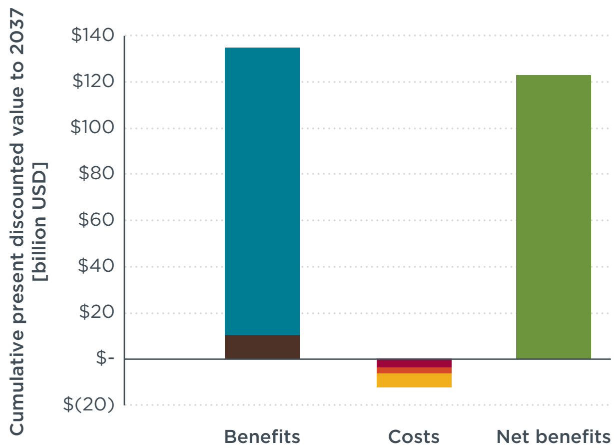


Figure 1 Timeline for implementation of nationwide emissions standards for diesel HDVs (Miller, 2014)

- In 2037, the annual combined operating and technology costs of the regulation are projected to be $1.8 billion, while estimated health benefits alone are projected to be $22 billion to $30 billion.
- Costs include additional operating costs to end-users of 3.5 cents per liter of diesel consumed. This includes an incremental cost of 2.5 cents per liter for ULSD and direct costs for DEF. Incremental vehicle technology costs are estimated to average $5,300 per vehicle.
- The benefits include prevention in the year 2037 of an estimated:
  - 6,800 premature deaths from exposure to $PM_{2.5}$ emissions in urban areas
  - 24,000 tons of $PM_{2.5}$ and 410,000 tons of NO_x
  - 54 million tons of CO_2-equivalent ($MtCO_2e$) using GWP-20, and 15 $MtCO_2e$ using GWP-100

Discounted annual costs and benefits can be summed over the period of 2018-2037 to assess the total net benefits of implementing the regulation over this period. As shown in Figure 2, the estimated benefits of the regulation (134 billion USD) are eleven times the total direct and indirect costs (12 billion USD). Subtracting costs from benefits yields estimated net benefits of 123 billion USD. Most of this value is the result of premature mortalities avoided due to significant reductions in $PM_{2.5}$ emissions.



	Benefits	Costs	Net benefits
Health benefits	$124	$-	$-
Climate benefits GWP-20	$10	$-	$-
Cost of fuel standards	$-	$(6)	$-
Cost of DEF	$-	$(2)	$-
Cost of vehicle technologies	$-	$(4)	$-
Net benefits	$-	$-	$123

Figure 2 Cumulative net benefits of NOM 044 (2018-2037)

While this regulation will not inherently present direct, quantifiable benefits for the users of new vehicles, this analysis take a societal perspective. In this regard, "cost-effective" means that the societal benefits of the regulation—in the form of reduced risk of premature death and mitigation of climate pollutants—greatly exceed the direct costs to the vehicle users and manufacturers. While not quantified here, the regulation will likely result in real improvements in the efficiency of new engines sold in Mexico; the resulting fuel savings to end-users could offset a substantial portion of the direct costs of the regulation.

1 Introduction

Mexico is planning to revise its existing emissions standards for diesel heavy-duty vehicles (HDVs). The current Norma Oficial Mexicana 044 (NOM 044) standards require new vehicles to meet either U.S. Environmental Protection Agency (EPA) 2004 or Euro IV standards. Changes to NOM 044 standards would require manufacturers of new heavy-duty vehicles to meet either EPA 2010 or Euro VI standards. The implementation of these vehicle standards will be coordinated with the nationwide availability of ultralow-sulfur diesel (ULSD) with fewer than 15 parts per million (ppm) sulfur, which is anticipated to be achieved under a separate regulation by October 2017. This analysis assumes full implementation of revised vehicle standards starting January 1, 2018. The purpose of this paper is to report on the results, methods, and underlying assumptions of a cost-benefit analysis that the ICCT conducted to support the decision-making process for updating NOM 044. The results of this analysis, as well as other technical considerations (e.g., equivalency of EPA 2010 and Euro VI standards) are summarized in the ICCT working paper *Revising Mexico's NOM 044 standards: Considerations for decision-making* (Blumberg et al., 2014).

International context of heavy-duty emission standards

Current NOM 044 standards, last updated in 2006, fall behind eight of the top vehicle markets, five of which have adopted world-class standards equivalent to EPA 2010 or Euro VI for HDVs (TransportPolicy.net, 2014). EPA 2010 and Euro VI are functionally equivalent standards, which take advantage of commercially available and cost-effective technologies capable of reducing emissions of particulate matter (PM) up to 98 percent and oxides of nitrogen (NO_x) by 89-96 percent below EPA 2004 levels (EPA, 2010a). As shown in Figure 3, the European Union, the U.S., Canada, Japan, and South Korea have adopted Euro VI or equivalent standards for HDVs.

The anticipated changes to Mexico's vehicle emissions standards, combined with the reduction in sulfur content of diesel fuel will primarily and significantly reduce emissions of fine particulates ($PM_{2.5}$), oxides of nitrogen (NO_x), volatile organic compounds (VOC), and their associated impacts on human health. The two compliance options, EPA 2010 and Euro VI, are functionally equivalent with respect to technologies, on-board diagnostics requirements, emission reductions, incremental costs, and improvements in efficiency over EPA 2004-compliant engines (Blumberg et al., 2014). In addition to requiring ULSD, vehicles compliant with EPA 2010 or Euro VI standards require diesel exhaust fluid (DEF), a mix of water and urea, for Selective Catalytic Reduction (SCR) technologies to operate correctly. DEF supply has not been a constraint in other countries such as Brazil that have introduced SCR technologies at a large scale, as a result of DEF suppliers entering the market to satisfy demand from new vehicles.

Cost-benefit analysis to support regulatory decisions

The U.S. EPA has developed a comprehensive framework for application of cost-benefit analyses to support the development of environmental regulations. Recent examples include regulatory impact analyses for EPA's 2007 and 2010 model year emissions standards for heavy-duty vehicles, engines, and diesel fuel sulfur, and Tier 2 and Tier 3 light-duty vehicle emissions and fuel standards. Following the EPA's pattern for U.S. environmental regulations, the ICCT completed an analysis of the costs and benefits of Mexico moving to EPA 2010 or Euro VI emission standards for diesel heavy-duty vehicles (HDV), capturing the most important benefits for health and climate, direct technology costs of the standards,

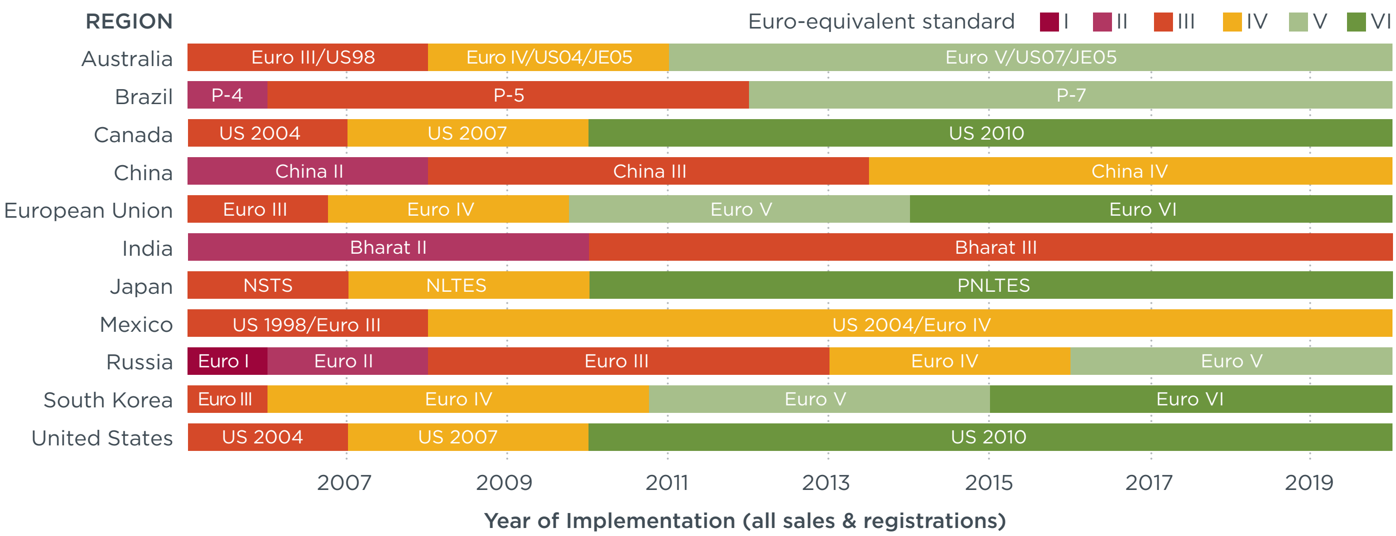


Figure 3 Timeline for implementation of nationwide emissions standards for diesel HDVs (Miller, 2014)

and marginal operating costs for diesel exhaust fluid (DEF) and ULSD.

The costs and benefits of the proposed changes to the NOM 044 regulation were estimated in comparison to maintaining the current emission limits. Accordingly, national emissions from diesel HDVs and their associated climate and health impacts were estimated under two modeling scenarios: a business-as-usual (BAU) or baseline scenario in which new diesel HDVs continue to meet the current EPA 2004 or Euro IV standards, and a regulation scenario in which new vehicles meet EPA 2010 or Euro VI standards starting in model year 2018. In the regulation scenario, diesel HDVs model year 2018 and later are assumed to be supplied with ULSD and DEF that allow proper functioning of emission controls. The results of this cost-benefit analysis as well as other technical considerations (e.g., equivalency of EPA 2010 and Euro VI standards) are summarized in the ICCT working paper *Revising Mexico's NOM 044 standards: Considerations for decision-making* (Blumberg et al., 2014). This paper focuses in detail on the methods, underlying assumptions, and results of the cost-benefit analysis.

Uncertainty analysis

The cost-benefit methods employed in this analysis are broadly consistent with those utilized by the EPA as described in its *Guidelines for Preparing Economic Analyses* (EPA, 2010c). Key similarities include evaluating the regulatory intervention against a realistic baseline, using discounting to appropriately compare costs and benefits over time, considering the most important determinants of costs and benefits, conducting an analysis of uncertainties, and evaluating the effects of remaining uncertainties on the potential outcome of the analysis. This analysis does not, however, assess in detail the distributional economic impacts of the proposed regulation or model the effects on demand of changes in vehicle and fuel prices. Several costs and benefits were not estimated due to their complexity and likely small impact on the outcome of the analysis. Among these are:

- Net fuel savings as a result of engine improvements enabled by SCR systems that exceed any fuel penalties incurred by diesel particulate filters (DPF); such savings will likely be addressed under a separate fuel efficiency or GHG standard
- Costs to maintain EPA 2010 or Euro VI-compliant vehicles compared to EPA 2004 vehicles
- Benefits of reduced morbidity and premature mortality from ozone and secondary $PM_{2.5}$
- Avoided climate impacts of reduced NO_X emissions
- Direct benefits to agricultural productivity as a result of reduced black carbon (BC) emissions

The inclusion of such components would influence the total estimates of benefits and costs but would not be expected to change the outcome of the cost-benefit analysis. Sensitivity analyses were also undertaken to examine the impacts of variability in factors that influence the quantified costs and benefits of the regulation; the results of these analyses, as well as implications of uncertainties that could not be quantified are discussed in greater detail in Chapter 3.

2 Methods

To minimize the impact of uncertainties related to modeling and evaluating costs and benefits, conservative assumptions were consistently chosen for this analysis. Such conservative assumptions include the consideration of the marginal cost of ULSD, which is anticipated in a separate regulation; moderate to low projections for growth of new heavy-duty vehicle sales; and the choice of a 20-year time horizon for estimating the net present value of the regulation.

The regulation was evaluated over a 20-year time horizon as opposed to in a single target year for several reasons. While the proposed standards are expected to apply to all new heavy-duty diesel vehicles starting in 2018, it will take several years for vehicles compliant with the updated standards to account for the majority of vehicles on the road. Moreover, while most of the costs of the proposed standards will be incurred upfront when new vehicles are sold, the emissions reductions will take place over the lifetime of these vehicles, and the associated climate and health benefits of reduced emissions extend even further. The U.S. EPA estimates that the health benefits of avoided premature deaths from air pollution should be distributed over twenty years following the exposure to emissions in a given year (EPA, 2011). Similarly, the climate benefits from reduced emissions are expected to continue many years beyond the timeframe over which the regulation costs are incurred (IWGSCC, 2010). Since individuals and society as a whole tend to prefer benefits today over future benefits, future benefits and costs have been discounted to facilitate comparison of the cumulative benefits and costs of the regulation (EPA, 2010c).

PROJECTION OF VEHICLE SALES AND ACTIVITY

The number of vehicles affected by the regulation is an important driver of benefits and costs. Since the regulation would apply only to model year 2018 and later vehicles, it is necessary to differentiate between the sale of new and used vehicles, which together account for total vehicle sales. As seen in Figure 4, in the past several years, used vehicle sales have grown faster than new vehicle sales, accounting for 35% of total vehicle sales in 2013. Recognizing that sales of used vehicles have grown relatively quickly but in the absence of long-term data with which to develop more concrete forecasts, the share of used vehicles is assumed to grow to 40% of total vehicle sales, while total vehicle sales are assumed grow roughly at historical rates (linear trend line). Conservative assumptions were chosen to ensure that benefits are not overestimated. The MOVES analysis line in figure 4 shows the total heavy truck and bus sales included in this analysis, within the context of historical sales of new and used vehicles.

The assumptions in this analysis result in lower estimates of growth in new vehicle sales (3 percent per year) than could have been warranted using an income elasticity approach. ANPACT, the association of Mexican truck and bus manufacturers, estimates that total vehicle sales from 1993-2010 grew faster than economy-wide gross domestic product (GDP), reflecting an income elasticity of 1.37. Coupled with long-term forecasts of GDP growth at 2.6 percent per year (Goldman Sachs Economic Research, 2007), total vehicle sales could be expected to grow at more than 3.5 percent per year if forecast using an income elasticity approach.

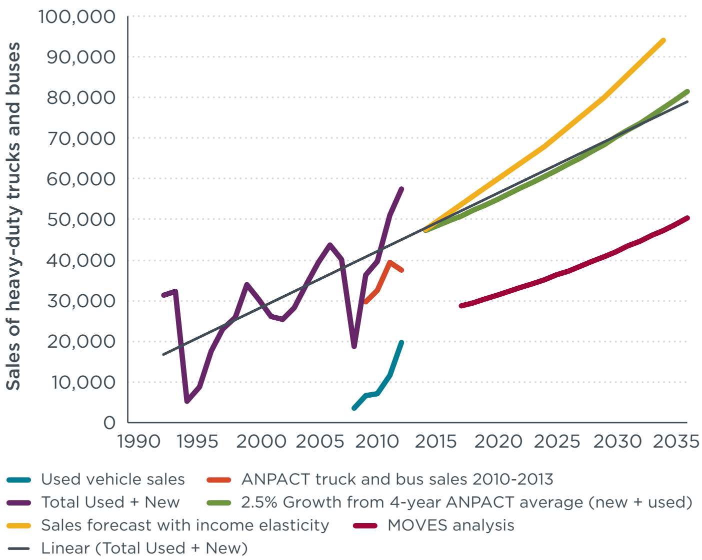


Figure 4 Historical and projected sales of heavy-duty trucks* and buses, 1993-2037
Data sources: ANPACT (2013) & INECC (2012).
* ANPACT sales data exclude medium-duty trucks (class 2b and 3). Sales of these classes of vehicles are assumed to grow at the same rate as heavy-duty trucks and buses shown above.

Projected sales by vehicle type, including medium-duty vehicles (Diesel HD Pickup) in addition to heavy trucks and buses (Diesel Vocational and Diesel Tractor), are shown in Figure 5. Vehicles tend to be driven less each year as the age of the vehicle increases, a trend known as vehicle kilometer traveled (VKT) degradation. Figure 6 shows estimates of VKT per vehicle by age from a survey of in-use vehicles done for the National Institute of Ecology and Climate Change (INECC, 2012). Since the proposed changes to the NOM 044 regulation would apply to new vehicles starting in 2018, any vehicles sold before 2018 will be unaffected by the change in emission standards. Figure 7 demonstrates how the total number of VKT traveled by vehicles affected by the regulation changes over time. Initially, total affected VKT increases very quickly. For example, VKT by model year (MY) 2019 vehicles are added to VKT by MY2018 vehicles (then one year old) in calendar year 2019, resulting in a near doubling of the total VKT affected by the new regulation from calendar year 2018 to 2019.

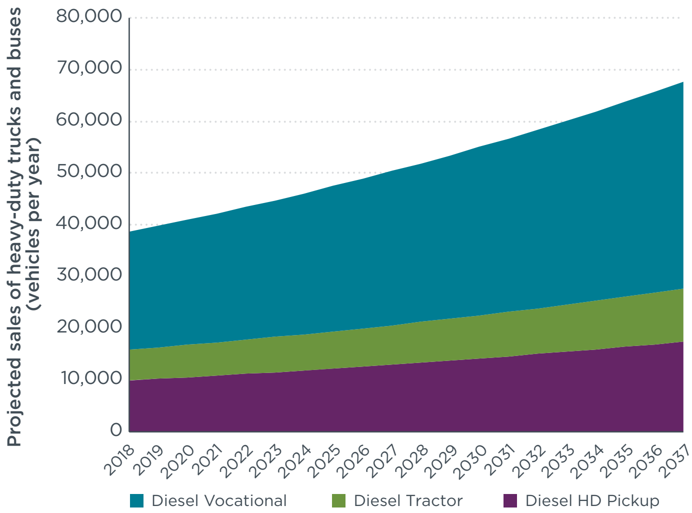


Figure 5 Projected sales of heavy-duty trucks and buses, 2018-2037

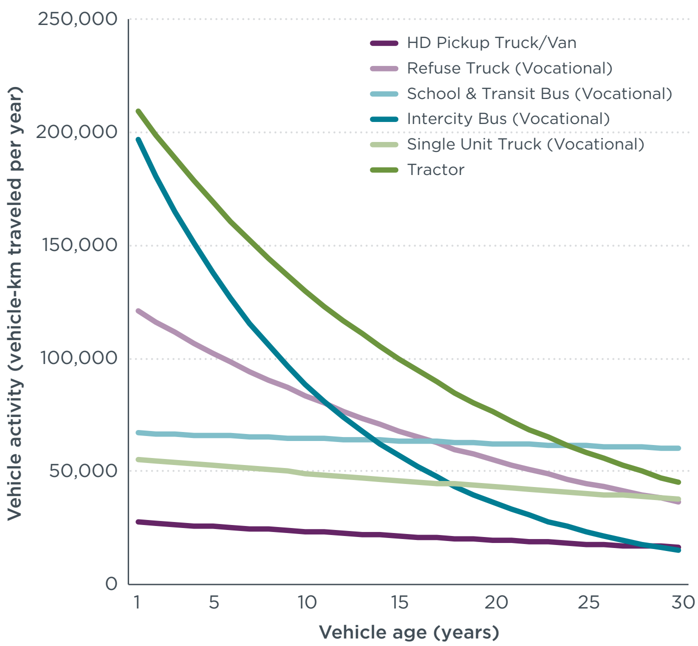


Figure 6 Vehicle-km traveled by age and vehicle type
Data source: INECC (2012)

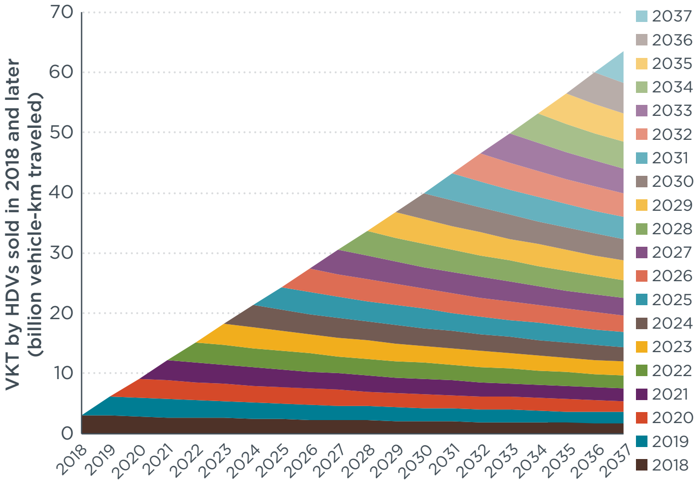


Figure 7 VKT by HDVs sold in 2018 and later by model year, 2018-2037

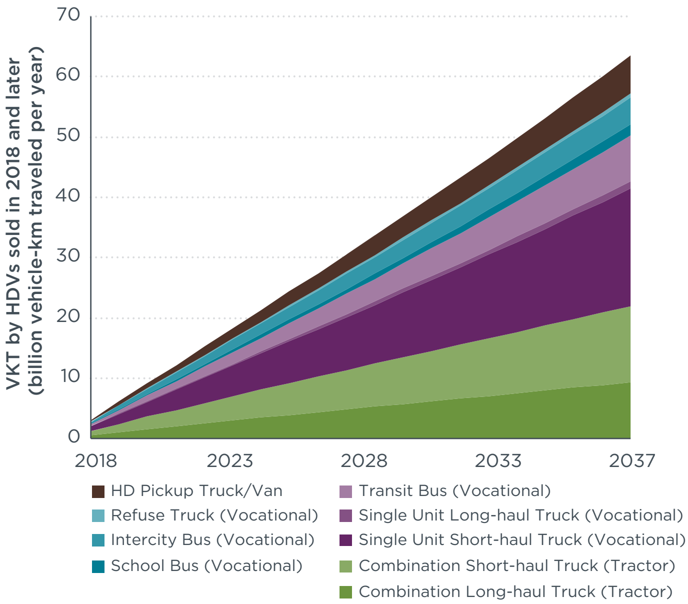


Figure 8 VKT by HDVs sold in 2018 and later by vehicle type, 2018-2037

ESTIMATION OF VEHICLE EMISSIONS

The U.S. EPA developed the Motor Vehicle Emission Simulator (MOVES) to estimate the benefits of vehicle emission regulations in the United States (EPA, 2010a). MOVES estimates fleet-wide emissions and fuel consumption from on-road vehicles and allows customization of vehicle fleet characteristics, including sales and activity by vehicle type, projected sales growth, and timelines for the implementation of differing levels of emission control. The ICCT adapted a version of MOVES 2010a for Mexico using Mexico-specific data on vehicle sales, activity per vehicle, and projected sales growth (described in the previous sections) to estimate emissions of local air pollutants from diesel HDVs. Key outputs of this analysis included tank-to-wheel (TTW) CO_2, PM, BC, and NO_x emissions with and without changes to Mexico's emissions standards, for the period 2018 to 2037. While Euro VI and EPA 2010 standards are functionally equivalent with respect to the technologies required and associated emissions reductions achieved, the same cannot be said for the current standards, which allow vehicles to meet either Euro IV or EPA 2004 requirements. EPA 2004 emissions levels are less costly to meet than Euro IV, which has resulted in EPA 2004 vehicles accounting for roughly 90 percent of the new-vehicle market in Mexico (Blumberg et al., 2014). To better account for the difference in baseline and regulation emissions, the ICCT selected MOVES, which is based on U.S. standards, rather than the European Environment Agency's COPERT emission factor model. Table 1 summarizes the forecast contribution of each vehicle type in 2018 to heavy-duty emissions, fuel consumption, activity, and sales in the BAU scenario.

Table 1 Share of sales, activity, fuel consumption, and emissions by vehicle type in BAU scenario

Vehicle type	Sales	VKT	Fuel & CO_2	PM	NO_x
HD Pickup Truck/Van	**26%**	**11%**	**7%**	**4%**	**5%**
Light Commercial Truck	26%	11%	7%	4%	5%
Tractor	**15%**	**40%**	**35%**	**33%**	**33%**
Combination Long-haul Truck	6%	17%	16%	16%	17%
Combination Short-haul Truck	9%	23%	19%	17%	17%
Vocational Vehicle	**59%**	**49%**	**58%**	**64%**	**62%**
Intercity Bus	4%	9%	15%	17%	14%
Refuse Truck	1%	1%	1%	1%	1%
School Bus	3%	3%	1%	1%	1%
Single Unit Long-haul Truck	2%	1%	2%	2%	2%
Single Unit Short-haul Truck	38%	24%	29%	32%	33%
Transit Bus	11%	11%	10%	11%	10%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

Using MOVES emissions outputs (measured in tons) and estimates of activity by vehicle type (measured in VKT), new fleet average emission factors were calculated to ensure reasonableness of emissions estimates. The emission factors differ from certification values in that they reflect the in-use effects of emission control technologies. For example, while the certification value for PM is 10 mg/bhp-hr, manufacturers have used diesel particulate filters (DPFs) for compliance, resulting in much lower average emissions. As a result, the PM emission factor of the in-use vehicle will be based on its actual emissions, converted to mg/km based on fuel consumption, rather than the certification limit. The calculated emission factors for PM (mg/km) and NO_x (g/km) are shown in the following table.

Table 2 PM and NO_x emission factors extracted from MOVES

Vehicle type	PM (mg/km)		Percent PM reduction	NO_x (g/km)		Percent NO_x reduction
	Current regulation	Revised regulation		Current regulation	Revised regulation	
HD Pickup Truck/Van	**108**	**6.8**	**94%**	**3.2**	**0.6**	**81%**
Light Commercial Truck	108	6.8	94%	3.2	0.6	81%
Tractor	**211**	**4.4**	**98%**	**4.9**	**0.2**	**95%**
Combination Long-haul Truck	236	5.2	98%	5.9	0.2	96%
Combination Short-haul Truck	192	3.8	98%	4.3	0.2	95%
Vocational Vehicle	**322**	**4.9**	**98%**	**7.1**	**0.3**	**96%**
Intercity Bus	434	10.0	98%	8.4	0.5	94%
Refuse Truck	209	2.2	99%	4.0	0.1	97%
School Bus	97	2.2	98%	2.0	0.1	93%
Single Unit Long-haul Truck	390	3.7	99%	9.2	0.3	97%
Single Unit Short-haul Truck	312	3.0	99%	7.4	0.2	97%
Transit Bus	287	5.7	98%	6.1	0.3	94%
Average	**259**	**4.8**	**98%**	**5.9**	**0.3**	**95%**

ESTIMATION OF HEALTH BENEFITS

The emissions reduced by the proposed regulation will result in health benefits that can be quantified and monetized. The ICCT has developed a methodology for assessing the number of avoided premature mortalities from a reduction in tailpipe $PM_{2.5}$ emissions in urban areas (Chambliss et al., 2013; Minjares et al., 2014).[1] For cost-benefit analysis, it is important to attribute health impacts to the year when they occur, rather than the year in which emissions were

1 For additional details on the health impacts methodology, see Appendix III of *The Impact of Stringent Fuel and Vehicle Standards on Premature Mortality and Emissions* (Chambliss et al., 2013).

generated. To this end, we introduce a 20-year distributed lag structure for mortality impacts, applying the methodology used by EPA in assessing the costs and benefits of reducing air pollution (EPA, 2011).[2] This analysis considers all costs and benefits that occur between 2018 and 2037, twenty years after the proposed implementation of the regulation. While benefits are expected to continue to accrue long after this time period, any avoided cases of premature mortality occurring after this timeframe, even if a result of emissions reductions within the timeframe, are not considered in this assessment.

Health impacts in urban areas

Since health impacts are based on population exposure to emissions, more weight is given to reductions in emissions from vehicles that have a high share of travel in densely-populated urban areas (Table 3). Buses are estimated to have the highest share of travel in urban areas, followed by heavy-duty pickups and other vocational vehicles.

Table 3 Share of emissions in urban areas by vehicle type (based on Chambliss et al., 2013)

Vehicle type	2018-2037
HD Pickup	31%
Bus	49%
Other vocational	26%
Tractor	17%

Monetization of health impacts

The benefits of avoided premature deaths from exposure to vehicle emissions were monetized using the Value of a Statistical Life (VSL) approach, which has been widely used to monetize the health benefits of environmental policies (EPA, 2000; EPA, 2011; Minjares et al., 2014). This approach "reflects the aggregation of individuals' willingness to pay for fatal risk reduction and therefore the economic value to society to reduce the statistical incidence of premature death in the population by one" (He and Wang, 2010). Ideally, VSL estimates should be derived from empirical data specific to the country of analysis; however, when sufficient data are not available, estimates can be made based on studies in other countries using a "benefit transfer" approach (Minjares et al., 2014).

The National Institute of Ecology and Climate Change (INECC) last updated its estimates of VSL in 2008; however, these estimates rely on empirical data from a single study and are unlikely to represent the preferences of the population in Mexico. INECC is in the process of revising these estimates based on new contingent valuation surveys (also known as "stated preference" surveys) in an effort to better represent the population in Mexico. Given the larger sample size and greater diversity of the studies considered in the EPA's meta-analysis, we opted to derive the main estimates of VSL for this analysis using a benefits transfer approach to adjust the EPA's estimates based on the difference in per-capita income between the U.S. and Mexico. While the main estimates adjust EPA's central value using the benefit transfer approach, Mexico-specific estimates are included as a sensitivity analysis; a similar approach was taken in a 2008 study at the Harvard School of Public Health (Stevens, 2008).

For analyses of environmental policies in the U.S., the EPA recommends using a central VSL estimate of $7.4 million (2006 USD) adjusted to the year of analysis (EPA, 2010b). This value was derived from a meta-analysis of 26 contingent valuation and labor market studies conducted predominantly for the U.S. population between 1976 and 1991. EPA adjusted the findings of these studies to 2006 dollars, fitted these values to a Weibull Distribution, and estimated a central value of $7.4 million. In 2010 dollars, this value is $8 million (Bureau of Labor Statistics, 2014).

The key assumption of the benefit transfer approach is that differences in per-capita income are the most important determinants of differences in willingness to pay for mortality risk reduction between populations. Other factors such as age and the type of fatality under consideration have a conceptual basis for influencing willingness to pay for mortality risk reduction, but more research is needed to reliably adjust for these factors (Minjares et al., 2014). The benefit transfer approach adjusts VSL based on the following equation, adapted from Hammitt and Robinson (2011):

$$VSL_b = VSL_a \; X \; \frac{PPP\ GNI\ per\ capita_b^{\,e}}{PPP\ GNI\ per\ capita_a}$$

Where country *a* is the country for which the original VSL estimate was derived, country *b* is the target country of the analysis, *PPP GNI per capita* is the gross national income per capita adjusted based on purchasing power parity, and *e* is the income elasticity. PPP GNI per capita is the World Bank's favored measure for assessing monetary well-being across countries (Minjares et al., 2014). The income elasticity

2 For this analysis, we consider the benefits and costs of the regulation from 2018 to 2037, twenty years after the planned implementation date. While annual net benefits of the regulation are expected to continue to grow after 2037 (especially considering that many heavy-duty vehicles remain in the fleet longer than 20 years), using a twenty-year analytical timeframe results in conservative estimates of the regulation's benefits and reduces the uncertainties associated with long-term projections of vehicle sales, population, and income. Coincidentally, this timeframe coincides with the EPA's recommended method to distribute the mortalities avoided from a reduction in emissions over a period of twenty years; so, closing the analytical timeframe in 2037 means that all mortalities avoided from the first year of emissions reductions (2018) are counted, while only a portion of the mortalities avoided from emissions reductions in each of the following 19 years are incorporated into the assessment of benefits.

represents the percent increase in willingness to pay (WTP) for a reduction in mortality risk that accompanies a percent increase in per-capita income. With increasing income, for example, an elasticity of 0.5 means that for a 10 percent increase in income, VSL increases by 5 percent. With a decrease in income (as with the benefit transfer approach), the same elasticity of 0.5 means that for a 10 percent decrease in income, VSL decreases by 5 percent. Thus when transfering VSL estimates from a high income country to a lower income country, high elasticities (e.g. 2.0) result in lower VSLs than low elasticities (0.5), since VSL is more sensitive to changes in per-capita income.

Studies have estimated a range of income elasticities, from 0.5 to 0.6 (Viscusi & Aldy, 2003) and 0.8 (OECD, 2012) in developed countries, to 1.0 as a central estimate based on recommendations by World Bank staff (Minjares et al., 2014), and greater than 1.0 in lower income populations (Hammitt & Robinson, 2011). The main estimates for this paper apply an income elasticity of 1.0. The section on sensitivity analysis of health benefits includes results for an elasticity range of 0.5 to 2.0.

Table 4 outlines the steps taken to derive a main estimate of VSL for Mexico.

Table 4 Estimation of VSL for Mexico, 2018-2037

Process	Result	Source
1. Identify a central VSL estimate based on studies of the U.S. population	7.4 million (2006 USD), published in 2010[3]	EPA (2010b)
2. Adjust EPA VSL estimate from 2006 dollars to 2010 dollars	8 million (2010 USD)	BLS (2014)
3. Compare per-capita income between Mexico and the U.S. in 2010 (PPP GNI per capita)	0.3 (14,700 / 48,300)	World Bank (2014)
4. Identify long-term projected growth rate of Mexico's real per-capita income[4]	2.2%	OECD (2014)
5. Compare per-capita income forecast for Mexico (2018 and 2037) to the 2010 U.S. per-capita income	2018: 0.36 (17,500 / 48,300) 2037: 0.55 (26,500 / 48,300)	World Bank (2014) & OECD (2014)
6. Select income elasticity	1.0 (0.5 to 2.0 for sensitivity)	Minjares et al. (2014)
7. Project VSL based on income elasticity and growth rate in per-capita income, 2018-2037 (in real 2010 USD)	2018: \$2.9 million 2037: \$4.4 million	–
8. Sensitivity analysis over a range of income elasticities	2018: \$1.1 to 4.8 million 2037: \$2.4 to 5.9 million	–

ESTIMATION OF CLIMATE BENEFITS

The climate impacts of reductions in black carbon, organic carbon, and sulfates were evaluated using Global Warming Potentials (GWP) for a 20-year and 100-year time horizon. Since the climate pollutants reduced by the regulation are primarily short-lived climate pollutants, the benefits of these emission reductions as reported in the results have been evaluated using GWP-20 (Table 5).

Monetization of climate benefits

In 2010, the U.S. government published an analysis of the social cost of carbon (SCC) for use in regulatory impact analyses conducted by U.S. agencies. In this publication, the following definition was applied for the social cost of carbon: "The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased

Table 5 Global warming potential of climate pollutants

	GWP-20	GWP-100	Source / Notes
CO_2	1	1	By definition, GWP normalizes climate impact based on CO_2.
BC	3200	900	IPCC Fifth Assessment Report (Myhre et al., 2013)
OC	-160	-46	(Bond et al., 2011)
Sulfate	-160	-46	Due to modeling limitations, PM and BC were estimated directly, with the remainder of PM emissions attributed to OC and sulfates. Both were evaluated using the GWP of OC, which is estimated to have stronger climate cooling effects than sulfates. This assumption yields conservative estimates of the net climate benefits of PM reductions.

3 The EPA does not provide specific guidance regarding the base year of its VSL estimate or how to adjust this estimate to the year of analysis. Accordingly, the EPA estimate was attributed to the year of publication (2010), and estimates were adjusted from 2006 dollars to 2010 dollars to ensure the real value is the same for both analyses.

4 Long-term projections of per-capita income typically use GDP per capita (PPP) rather than GNI per capita (PPP) as a measure of income; from 2010 to 2012, the ratio of these measures in Mexico held constant at 1.22 (GNI per capita to GDP per capita). Assuming this ratio will hold relatively constant over time, this analysis approximates long-term GNI per capita (PPP) growth at 2.2 percent per year, consistent with OECD projections of annual growth in GDP per capita (PPP) to 2037 (OECD, 2014).

flood risk, and the value of ecosystem services due to climate change" (IWGSCC, 2010).

The SCC has been widely researched, and estimates vary considerably. Tol (2009) identifed over 200 estimates of the SCC, with values ranging from $8 to $190 per ton CO_2 (in 2010 USD). Such analyses tend to estimate the impacts of emissions released in a given year, sum the present value of the damages resulting in the following years, and divide this by the number of tons emitted in the initial year. Since the impacts of such emissions will be experienced over the course of several generations, there is a precedent for using a lower discount rate to evaluate climate benefits that takes into account the preferences of future generations. The 2010 study of the Interagency Working Group on Social Cost of Carbon (IWGSCC) estimate the SCC for three discount rate scenarios: 2.5%, 3%, and 5%. The EPA has subsequently applied these values in several major regulatory analyses (EPA, 2014). The IWGSCC estimates indicate global averages; therefore these do not need to be adjusted based on the income of the region in which they are applied (as with VSL).

Since Mexico's government has not published its own valuation of the social cost of carbon, SCC values were selected which approximate the lower end of the range of identified estimates. Tol (2009) identifies mean estimates ranging from $20 to $57 depending on the assumed pure rate of time preference (adjusted to 2010 USD). The IWGSCC's estimates using a 3% discount rate result in a 2010 value of $22.51, which falls at low end of this range. The corresponding SCC values adapted from IWGSCC (2010)'s 3% discount rate scenario range from $27 per ton in 2018 to $39 per ton in 2037. The IWGSCC recently revised its SCC estimates to about 50% higher than the initial values for 2010 (IWGSCC, 2013). While lower initial values from IWGSCC (2010) are applied in the main analysis to approximate the low end of the range of SCC estimates, both sets of estimates are examined as a sensitivity analysis in Chapter 3.

The SCC values used in this analysis reflect benefits to society of reducing a ton of CO_2 emissions. In the absence specific values derived for short-lived climate pollutants (SLCPs) such as BC, OC, and sulfates, the SCC is adapted to this analysis using 20-year GWPs for these pollutants (Minjares et al., 2014). The benefits of GHG reductions are assumed in this analysis to be societal; additional GHG trading or pricing strategies would be required in order to accrue any direct monetary benefits.

ESTIMATION OF VEHICLE TECHNOLOGY COSTS

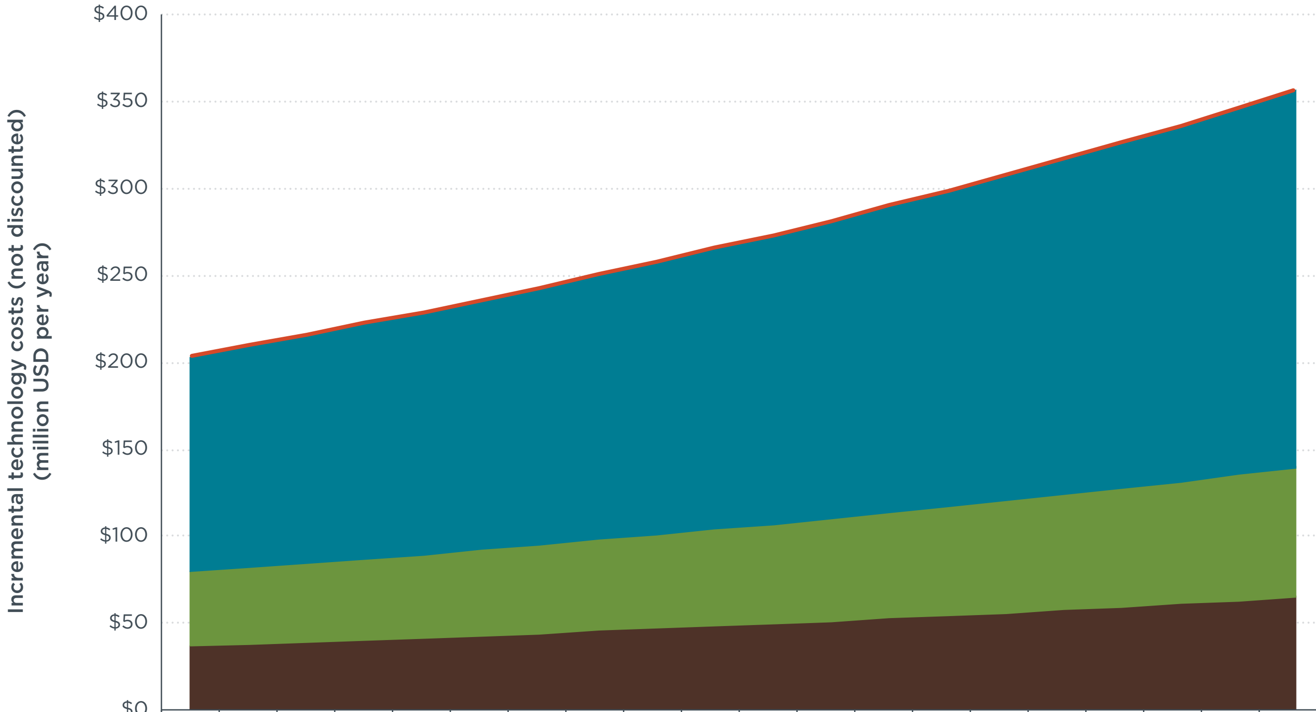
The ICCT is finalizing an engineering cost analysis of the components that go into meeting U.S. and European emissions standards (Posada Sanchez, 2014). Similar to the analysis that ICCT published in 2012 for light-duty vehicles (Posada Sanchez et al., 2012), the additional analysis considered the incremental costs of meeting more stringent standards for heavy-duty vehicles. The analysis derives the direct costs to manufacturers of new emissions standards, including variable costs that depend on engine displacement, such as catalyst volume, substrate, washcoat and urea injection system, as well as fixed costs, such as sensors, other components and accessories.

This analysis of the benefits and costs of changes to Mexico's heavy-duty emission standards takes as inputs the results of the engineering cost analysis. Incremental per-vehicle technology costs are estimated by subtracting the cost of meeting EPA 2004 standards from the cost of meeting EPA 2010/Euro VI standards. The estimated fleet-average incremental cost of moving from EPA 2004 to EPA 2010/Euro VI is around $5,300 per vehicle, with lower costs for smaller trucks and higher costs for long-haul trucks (Table 6). While the costs of emission control technology can be expected to decrease over time (EPA, 2000), this analysis conservatively assumes fixed per-vehicle technology costs over time. As additional research on technology-learning effects becomes available, it is recommended that these effects be incorporated into future analyses. In this case, incorporating technology-learning effects would further increase the net benefits of the proposed standard.

Fleetwide technology costs are the product of per-vehicle costs and new vehicle sales for each vehicle type. The total (undiscounted) cost of vehicle technology increases over time with new vehicle sales (Figure 9).

Table 6 Incremental technology cost per vehicle and vehicle sales

	Incremental cost per vehicle (EPA 2004 to EPA 2010/Euro VI)	Vehicle sales	
		2018	2037
HD Pickup Truck/Van		9,941	17,431
Light Commercial Truck	3700	9,941	17,431
Tractor		5,855	10,268
Combination Long-haul Truck	8491	2,492	4,369
Combination Short-haul Truck	6376	3,364	5,898
Vocational Vehicle		22,804	39,987
Intercity Bus	6376	1,590	2,787
Refuse Truck	6376	271	476
School Bus	5017	1,054	1,848
Single Unit Long-haul Truck	6376	863	1,513
Single Unit Short-haul Truck	5017	14,591	25,586
Transit Bus	6376	4,435	7,777
Total		**38,600**	**67,686**



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Vocational (diesel)	124	128	132	136	140	144	148	153	157	162	167	172	177	182	188	193	199	205	211	218
Tractor (diesel)	43	44	45	47	48	49	51	52	54	56	57	59	61	63	64	66	68	70	73	75
HD Pickup (diesel)	37	38	39	40	41	43	44	45	47	48	49	51	52	54	56	57	59	61	63	64
Total	**204**	**210**	**216**	**222**	**229**	**236**	**243**	**250**	**258**	**266**	**274**	**282**	**290**	**299**	**308**	**317**	**327**	**336**	**346**	**357**

Figure 9 Annual incremental technology costs of proposed regulation (2018-2037)

ESTIMATION OF DIESEL EXHAUST FLUID COSTS

Selective Catalytic Reduction (SCR) systems are the most widely used technology to meet NO_x emissions limits of EPA 2010/Euro VI standards for heavy-duty diesel vehicles. SCR systems require the use of Diesel Exhaust Fluid (DEF) to function properly and meet NO_x certification levels. While the level of DEF consumed varies depending on duty cycle, vehicle operation, etc., the industry standard is approximately two percent the volume of diesel fuel consumed (ARB, 2014). In this analysis, the consumption of DEF was estimated at two percent of total diesel fuel consumed by vehicles model year 2018 and later (Figure 10).

On a per-liter basis, DEF costs roughly 70 percent as much as diesel fuel in the U.S. This price ratio has held steady for several years. While the cost of DEF in Canada is similar to that in the U.S., due to the unknowns associated with DEF pricing in Mexico, this analysis uses a conservative value of 80 percent, approximately ten percent higher than prices in the rest of region. The price of DEF is linked to the increase in real fuel prices recommended by INECC (Integer, 2014; EIA, 2014).

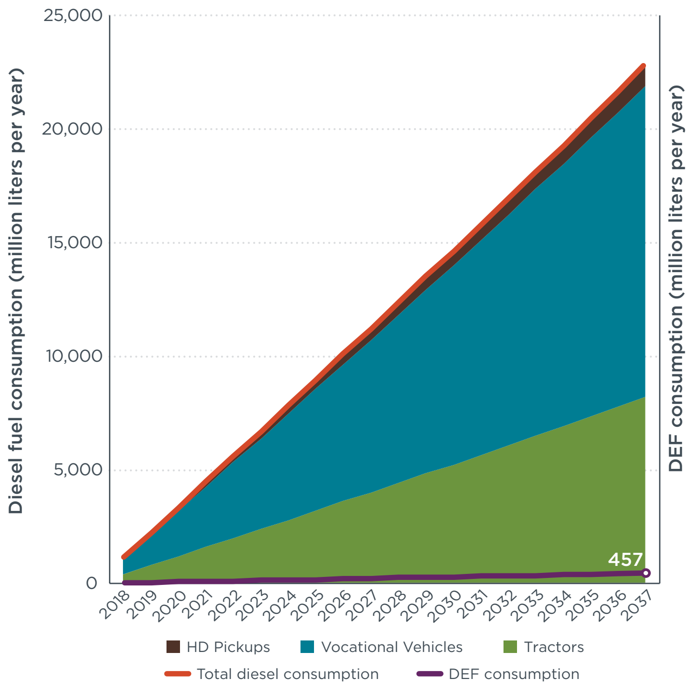


Figure 10 Annual consumption of diesel fuel and diesel exhaust fluid (DEF) by MY2018 and later heavy-duty vehicles (2018-2037)

ESTIMATION OF ULTRALOW-SULFUR FUEL COSTS

While fuels and vehicles have been regulated separately in Mexico, the ICCT considers fuels and vehicles as a system. To this end, this analysis includes the incremental costs of producing and refining ULSD to supply new vehicles subject to the regulation. These costs are estimated as the product of diesel fuel consumption by MY2018 and later heavy-duty vehicles and the marginal cost of ULSD, estimated at 2.5 U.S. cents per liter (Hart Energy and Mathpro Inc., 2012). This analysis uses country-specific investment parameters for the per-liter refining costs to achieve 10-ppm sulfur diesel at existing refineries in Mexico. Since approximately 30 percent of the diesel in Mexico is imported and is already available at 10-ppm sulfur levels, the actual incremental costs of ULSD could be expected to be lower than assessed in the analysis, which assumes a baseline fuel quality of 500 ppm sulfur (Hart Energy & MathPro Inc., 2012; PEMEX, 2013).

3 Results

EMISSIONS REDUCTIONS

Over the period of 2018-2037, the regulation will reduce emissions of $PM_{2.5}$ by 225,000 tons[5], BC by 160,000 tons, and NO_x by 4 million tons. Annual emissions reductions are shown in Figure 11.

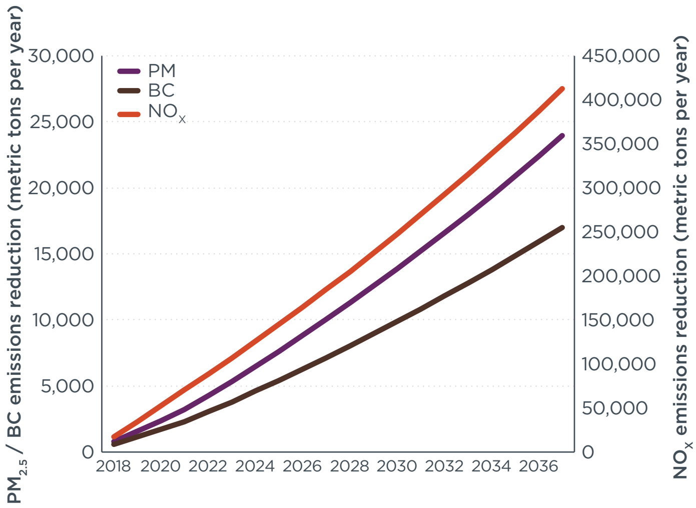
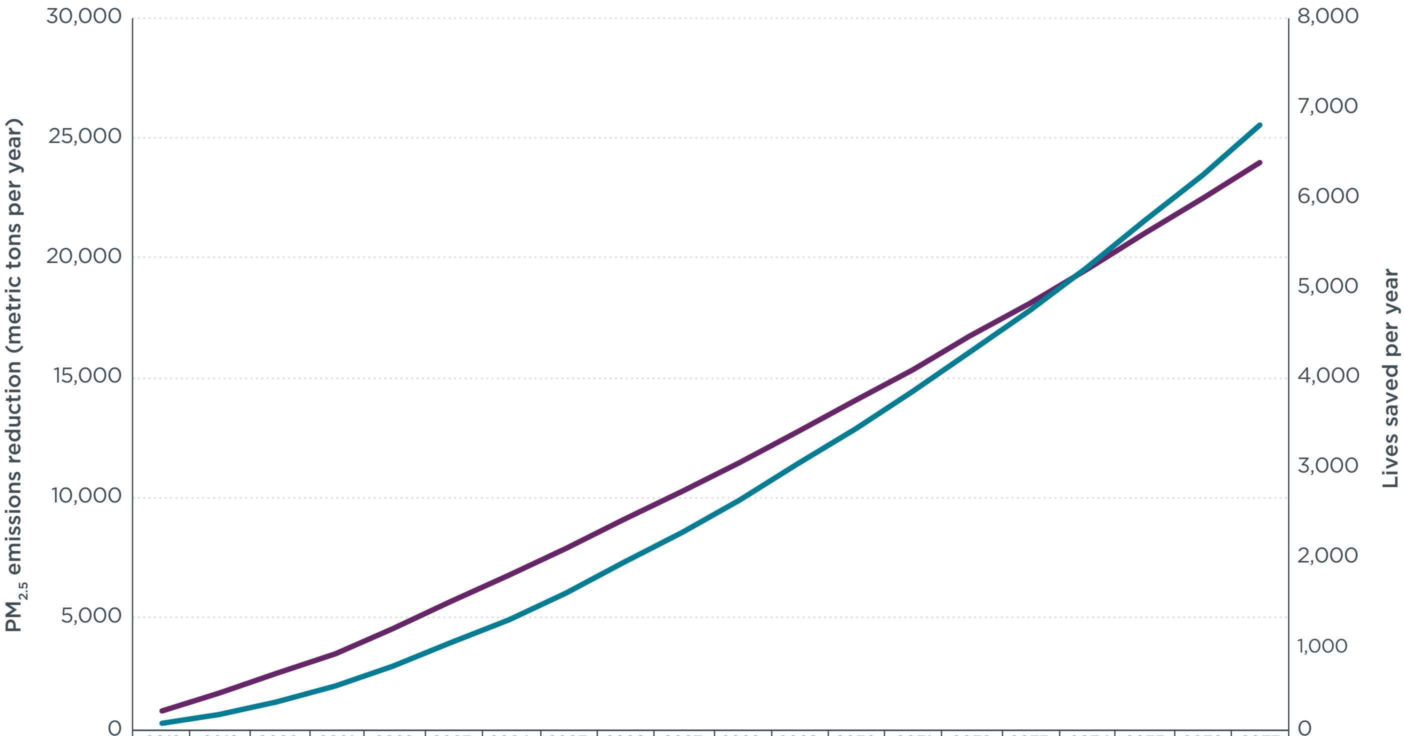


Figure 11 Reduction of $PM_{2.5}$, BC, and NO_x emissions



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
PM	779	1,573	2,384	3,212	4,274	5,359	6,490	7,646	8,837	10,053	11,304	12,583	13,891	15,230	16,600	18,002	19,437	20,907	22,413	23,955
Lives saved	70	172	309	482	712	965	1,243	1,547	1,876	2,223	2,591	2,977	3,383	3,808	4,255	4,722	5,210	5,720	6,252	6,807

Figure 12 Reduced $PM_{2.5}$ emissions and lives saved each year (2018-2037)

5 All tons reported are metric tons.

HEALTH AND CLIMATE BENEFITS

Over the time period of 2018 to 2037, the NOM 044 regulation is expected to avoid over 55,000 premature mortalities from cardiopulmonary disease, lung cancer, and acute respiratory disease caused by diesel vehicle emissions.

From 2018 to 2037, the regulation will reduce black carbon emissions equivalent to 512 million metric tons CO_2 (using GWP-20) or 144 million metric tons CO_2 (using GWP-100), about 2% of which will be offset by reductions in climate-cooling organic carbon and sulfate emissions (Table 7).

Table 7 Cumulative reduction in climate pollutant emissions (million metric tons of CO_2-equivalent)

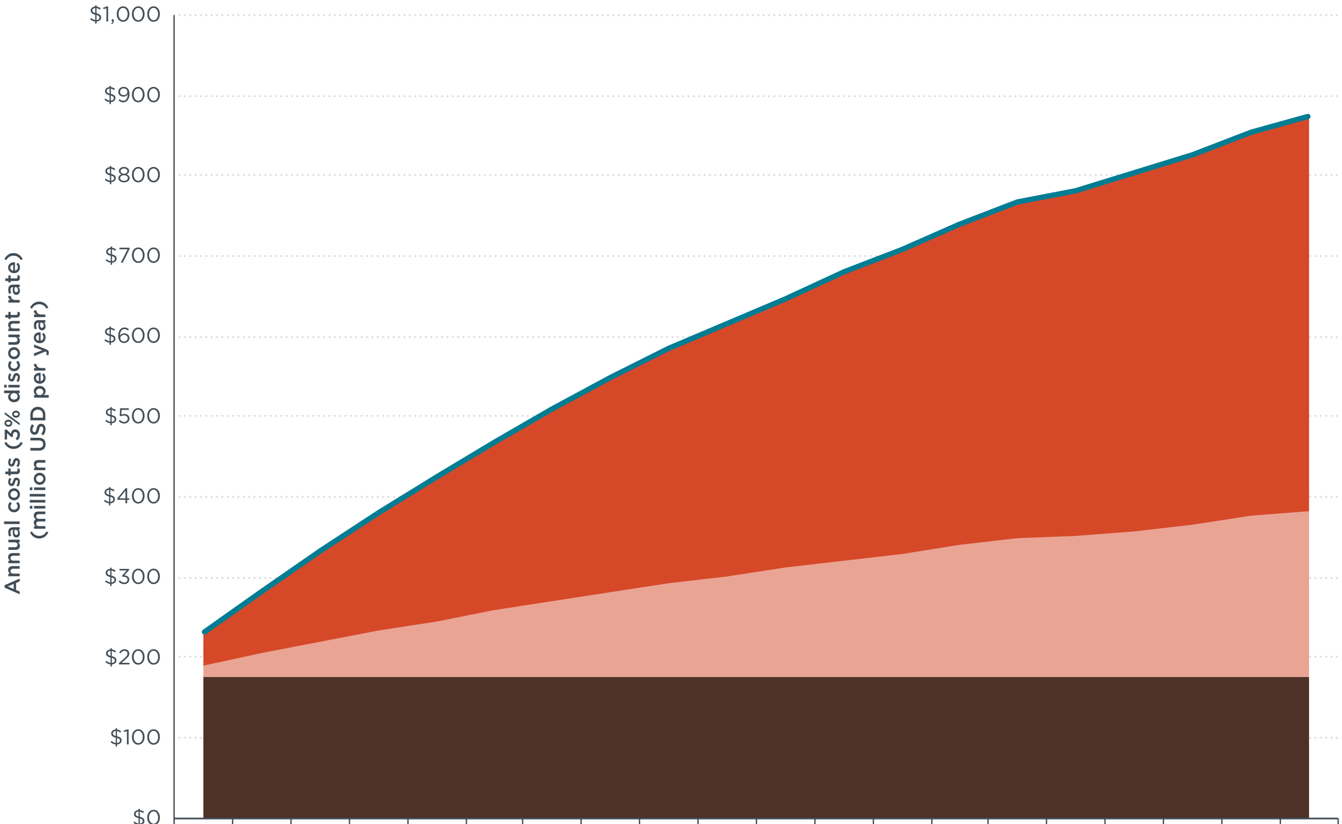
	$MtCO_2$-equivalent 2018-2037 (cumulative)		Share of net CO_2e (cumulative)	
	GWP-20	GWP-100	GWP-20	GWP-100
BC	512	144	102%	102%
OC & Sulfate	-11	-3	-2%	-2%
Net CO_2e	501	141	100%	100%

COSTS OF VEHICLE TECHNOLOGY, DIESEL EXHAUST FLUID, AND ULTRALOW-SULFUR FUEL

Total costs of the proposed regulation are shown in Figure 13. While the undiscounted cost of vehicle technology increases over time with projected sales growth, this growth rate is coincidentally the same as the three percent discount rate applied, causing discounted technology costs to appear constant. The costs of ULSD and DEF grow more rapidly, since these apply to both new vehicles sold in a given year and new vehicles sold in prior years (starting with MY2018).

PRESENT VALUE OF BENEFITS AND COSTS

Converting benefits and costs into present value terms using a discount rate allows comparisons to be made over time. The results for the main analysis use a discount rate of 3 percent based on input from INECC. Figure 14 presents the discounted annual benefits over time.



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Cost of fuel standards	40	77	113	147	178	208	237	264	290	313	335	357	377	398	417	429	443	458	476	489
Cost of DEF	16	30	45	58	71	84	96	107	118	128	137	147	156	166	175	178	184	191	202	208
Incremental tech. cost	176	176	176	176	176	176	176	176	176	176	176	176	176	176	176	176	176	176	176	176
Total cost	231	283	333	381	425	468	508	548	584	616	648	679	709	739	768	783	803	825	853	873

Figure 13 Total costs of the proposed regulation using a three percent discount rate (2018-2037)

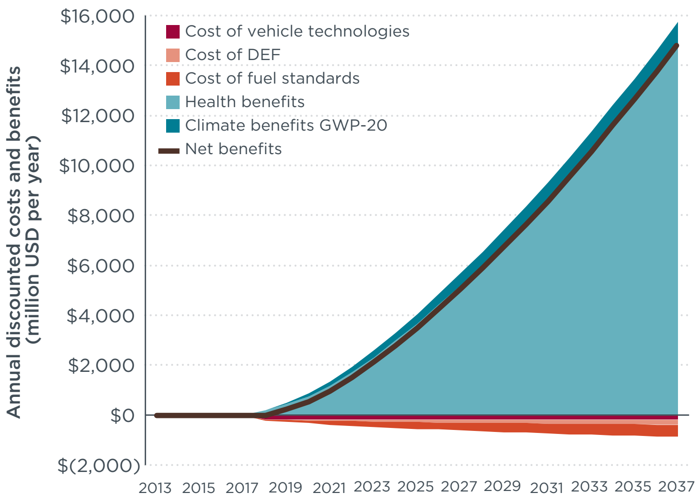
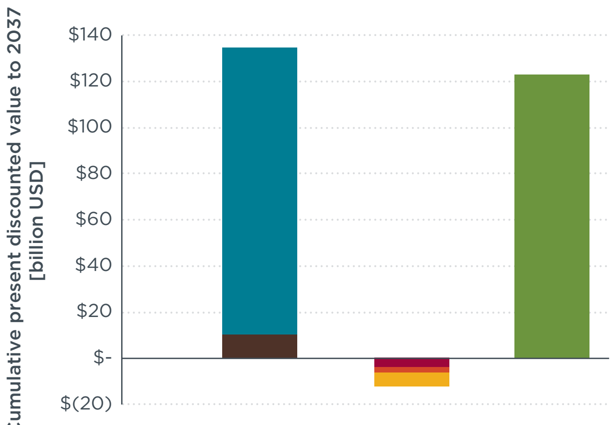


Figure 14 Present value of annual benefits and costs of NOM 044 (2018-2037)

Discounted annual costs and benefits can be summed over the period of 2018-2037 to assess the total net benefits of implementing the regulation over this period. As shown in Figure 15, the estimated benefits of the regulation (134 billion USD) are eleven times the total direct and indirect costs (12 billion USD). Subtracting costs from benefits yields estimated net benefits of 123 billion USD. Most of this value added results from the premature mortalities avoided as a result of reduced $PM_{2.5}$ emissions.



	Benefits	Costs	Net benefits
Health benefits	$124	$-	$-
Climate benefits GWP-20	$10	$-	$-
Cost of fuel standards	$-	$(6)	$-
Cost of DEF	$-	$(2)	$-
Cost of vehicle technologies	$-	$(4)	$-
Net benefits	$-	$-	$123

Figure 15 Cumulative net benefits of NOM 044 (2018-2037)

The sensitivity to discount rate is explored in the following section. The benefits far outweigh the costs for the full range of discount rates considered, although the estimated net present value of the regulation does vary depending on the choice of discount rate.

UNCERTAINTY ANALYSIS

It is important to consider the various uncertainties involved in order to ensure that the results of an analysis can be relied upon to credibly inform the potential effects of a regulation. With the aim of minimizing the effect of uncertainty on the reliability of these estimates, this section quantitatively evaluates the impacts of certain sources of uncertainty that may have a large impact on the estimation of benefits and costs (sensitivity analysis), and qualitatively discusses sources of uncertainty which cannot easily be quantified, but which could nonetheless influence the total benefits or costs of the proposed regulation.

Sensitivity of health benefits to VSL

The VSL is a key determinant of the monetized benefits of the proposed regulation. Given the influence of VSL on overall results and uncertainty regarding its exact value, sensitivity analysis was conducted to show the impact of considering differing estimates of VSL on the monetized health benefits of the proposed regulation. Differing estimates for VSL and their impacts on valuation of health benefits are shown in Figure 16. As described in Chapter 2, the ICCT derived VSL estimates using a range of income elasticities, including 0.5, 1.0, and 2.0, and compared these with estimates derived from INECC that use a mid-point value from a range of elasticities (0.5 to 2.0). The methods for INECC's estimates are more fully described in Stevens (2008).

As shown, estimates of VSL vary considerably, from $1.1 to 4.8 million in 2018 to $2.4 to $5.9 in 2037. The main estimates used in the analysis fall roughly in the middle, from $2.9 million in 2018 to $4.4 million in 2037. In all cases considered, the estimated health benefits of the proposed regulation alone far exceed the total estimated costs: in the year 2037, annual undiscounted health benefits range from $16 to $40 billion in 2037, compared to annual undiscounted costs of $1.8 billion.[6]

6 Values do not need to be discounted when comparing costs and benefits occurring within the same year.

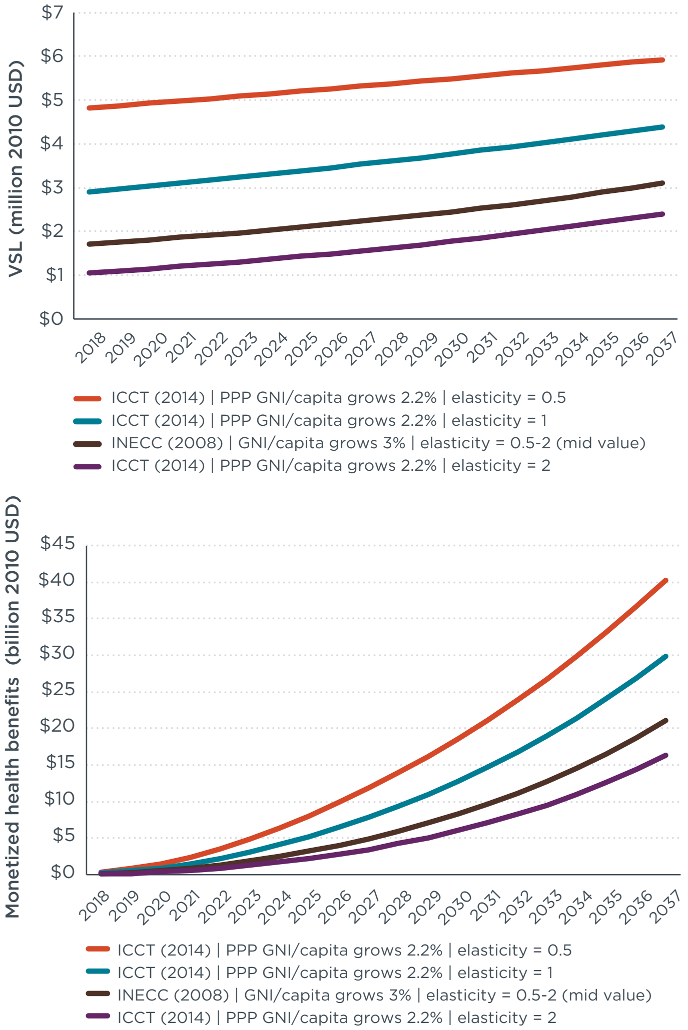


Figure 16 Sensitivity of annual monetized health benefits to VSL

Sensitivity to social cost of carbon

Since Mexico's government has not published its own valuation of the social cost of carbon, this analysis adapted SCC values derived in the U.S. (IWGSCC, 2010). These values were selected since they have a precedent for use in government analyses and approximate the lower end of the range of estimates identified in Tol (2009). Figure 17 summarizes the range of climate benefits (GWP-20) with IWGSCC's initial (2010) and revised estimates (2013) of the SCC. As shown, the choice of SCC has a considerable impact on the valuation of climate benefits, which in 2037 range from less than a billion USD to over $10 billion. The main estimate reported in this analysis (IWGSCC 2010 estimates using a 3% discount rate) falls in the lower end of the range, at $2.1 billion in 2037. Evaluating the impacts of SLCPs instead at GWP-100 would result in estimates about one-third their GWP-20 levels.

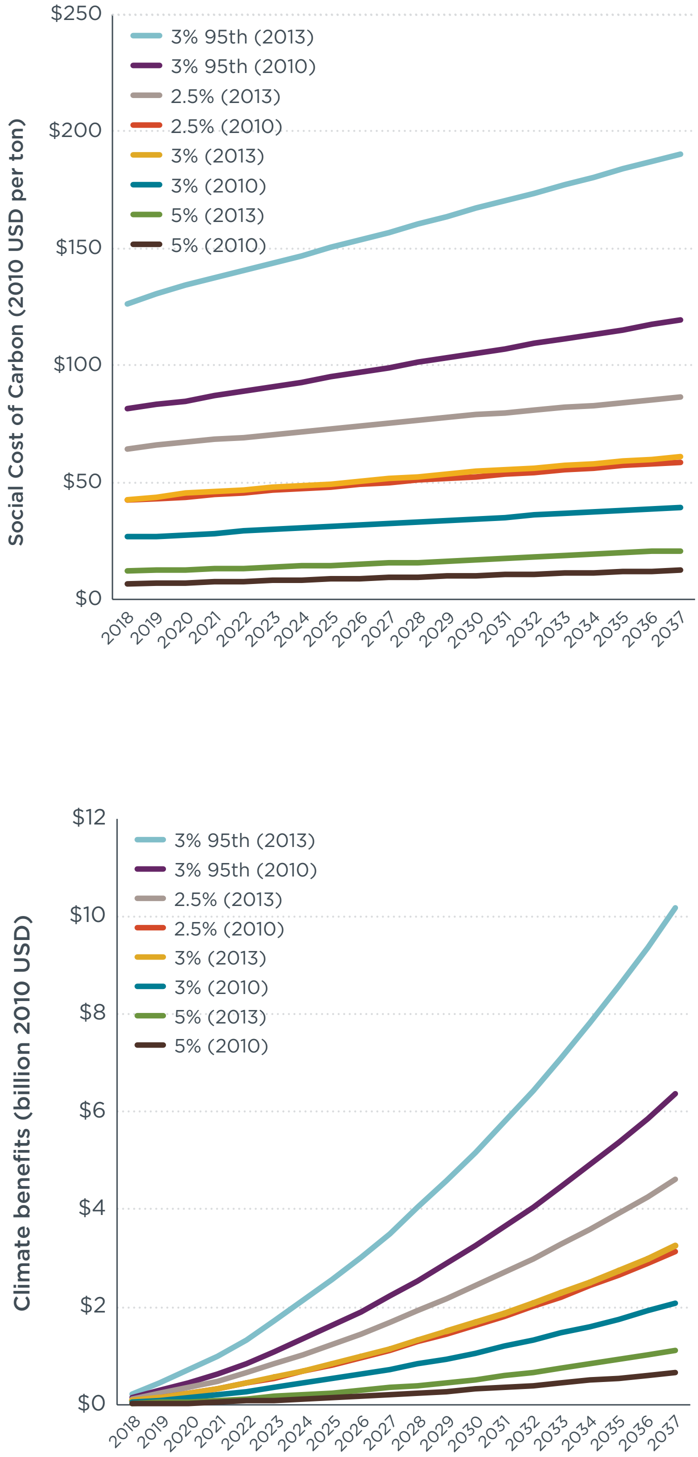


Figure 17 Sensitivity of annual climate benefits to social cost of carbon and discount rate

Sensitivity to discount rate and climate metric

For costs and benefits that scale together with time, the discount rate has a minimal impact on the ratio of benefits to costs; however, it does impact the cumulative net present value of costs and benefits over a period of time. Additionally, the discount rate is a key determinant of the magnitude of climate benefits as evaluated using the social cost of carbon, since these climate benefits can occur over several generations.[7]

In its *Guidelines for Preparing Economic Analyses*, the EPA contrasts two methods for estimating a discount rate. The first, the social rate of time preference, represents the rate at which individuals in society are willing to trade present consumption for future consumption and can be derived using the real interest rates of long-term government bonds (EPA, 2010c). Recent estimates of the social rate of time preference tend to be about 3 percent. The second, called the social opportunity cost of capital, is to be used in cases where a regulation displaces private sector investments dollar-for-dollar; in the U.S., the social opportunity cost of capital has been estimated at roughly 7 percent based on the pre-tax market returns to private investments (EPA, 2010c). In its regulatory analyses, the EPA has reported results for three discount rates: a 3 percent rate based on the case that no private investments are displaced, a 7 percent rate assuming private investments are displaced dollar-for-dollar, and a 5 percent rate that roughly averages the two. While the main analysis here applies a discount rate of 3 percent based on input from INECC, sensitivity analysis was conducted for rates of 5 percent and 7 percent.

The choice to evaluate climate benefits on a near-term or long-term horizon can influence the valuation of reducing short-lived climate pollutants. Table 8 indicates the sensitivity of cumulative benefits and costs to the selected discount rate and climate metric; the estimates in the first column indicate the main results, which are estimated for GWP-20 using a 3% discount rate. As shown, the benefits of NOM 044 are estimated to exceed the costs of implementation over a twenty-year timeframe by a factor of nine to eleven for the range of discount rates and climate metrics considered.

Table 8 Sensitivity of cumulative costs and benefits to discount rate and climate metric, 2018-2037

	GWP-20			GWP-100		
DISCOUNT RATE	**3%**	**5%**	**7%**	**3%**	**5%**	**7%**
Benefits (billion USD)	135	89	67	127	88	63
Costs (billion USD)	12	8.9	6.6	12	8.9	6.6
Net Benefits (billion USD)	**123**	**81**	**61**	**115**	**79**	**57**
Benefit-Cost ratio	11.2	10.1	10.2	10.6	9.9	9.6

Unquantified uncertainties

This analysis captures the most important benefits for health and climate, direct technology costs of the standards, and marginal operating costs for DEF and ULSD. Several components were not estimated and are therefore not included in the reported costs and benefits. Among these are:

- Net fuel savings
- Costs to maintain EPA 2010 or Euro VI-compliant vehicles compared to EPA 2004 vehicles
- Benefits of reduced morbidity and premature mortality from ozone and secondary $PM_{2.5}$
- Avoided climate impacts of reduced NO_x emissions
- Direct benefits to agricultural productivity as a result of reduced BC emissions

Table 9 summarizes the expected impacts of these factors on the net benefits of the regulation. Full consideration of these factors would not be expected to change the net benefits of the regulation dramatically but would be expected to result in an increase in estimated net benefits of the proposed regulation.

7 Some studies have made a case that low or near-zero discount rates should be used to evaluate climate impacts, which primarily affect future generations whose interests are not fully represented by current generations (Stern et al., 2006).

Table 9 Expected impacts of unquantified uncertainties on net benefits

Component	Reason for exclusion	Expected impact on net benefits
Fuel savings of new engine designs	Efficiency improvements enabled by SCR systems are expected to exceed any fuel penalties associated DPFs, leading to a net fuel efficiency benefit. While vehicle manufacturers have highlighted fuel efficiency benefits, there is a lack of published literature on the actual, in-use fuel savings of new vehicles as compared to EPA 2004 vehicles. While fuel savings are a relatively small benefit when compared to the much greater societal benefit associated with reduced health impacts, they may be very significant from the perspective of the vehicle user. Such fuel savings—on the order of several percent—have the potential to make up for the incremental costs for ULSD and DEF.	+
Vehicle maintenance costs	Lack of published literature on actual maintenance costs associated with new technologies and vehicles, as compared to EPA 2004 vehicles.	-
Health impacts of ozone and secondary PM	Evaluating impacts of ozone and secondary PM requires significant additional complexity, including atmospheric chemistry modeling and detailed projections of emissions from other sectors, while health benefits are still expected to be dominated by primary PM emissions reductions.	+
Climate impacts of NO_x	The science is still unclear on the precise impacts of NO_x. In the timeframe of this study it is expected to be slightly warming, while in the longer timeframe it is expected to be slightly cooling.	+/-
Agricultural impacts of BC	BC may have direct impacts on agricultural productivity that are not captured in Social Cost of Carbon estimates.	+

Expected impacts on net benefits classified as follows: + = small increase; - = small decrease; +/- = directionality unknown.

4 Conclusion

The results of the cost-benefit analysis indicate that updating NOM 044 emission standards to EPA 2010 or Euro VI requirements is highly cost-effective from a societal perspective, in that the environmental and health benefits to society far exceed the costs to end users to purchase and operate cleaner heavy-duty diesel vehicles in Mexico. The analysis was designed to minimize the impact of any uncertainties on the key outcome of whether the regulation is cost-effective. The results indicate that the cumulative net present value of the regulation to 20 years after implementation is $123 billion (2010 USD), with health benefits of $124 billion, climate benefits of $10 billion, and total costs of $12 billion. Sensitivity analyses were conducted using a range of assumptions regarding discounting and valuation of health and climate benefits; in all cases, the results indicate that the societal benefits of the regulation far outweigh the costs.

The magnitude of net benefits of the proposed regulation in Mexico indicate that such policies could add significant value in other countries that have yet to adopt international best practices to control conventional pollutant emissions from vehicles, especially those countries which have similar characteristics regarding per-capita income, motorization, and urbanization. Additionally, the cost-benefit methods applied here are transferable to other country contexts, where similar analyses could be completed to inform regulatory decision-making efforts.

In addition to the dramatic benefits to public health and climate of the proposed regulation in Mexico, moving to ULSD nationwide and EPA 2010 or Euro VI emissions standards brings Mexico substantially closer to harmonization across the transport sector with international best practice policies for clean vehicles and fuels. Two critical opportunities stand out:

1. Mexico's emissions standards for light-duty vehicles have also fallen behind recent progress in other top vehicle markets in the region: Brazil has begun type approvals for light-duty vehicles based on Euro 5 standards, and in early 2014 the U.S. adopted Tier 3 standards based on California's LEV III standards, which have the lowest emission limits for light-duty vehicles of any standard adopted to date. Mexico should ensure that light-duty vehicles are also taking advantage of improved emissions control technologies, especially for diesel vehicles.
2. Harmonizing fuel and emissions standards with EPA 2010 levels provides an important opportunity to also enact fuel efficiency standards for heavy-duty vehicles. Revising NOM 044 standards should both offer substantial fuel efficiency benefits and provide a good baseline for harmonization with U.S. Phase 1 and Phase 2 greenhouse gas standards for heavy-duty vehicles. In order to reap the full climate and energy benefits available, additional regulatory steps are needed. Harmonizing with U.S. efficiency standards for heavy-duty vehicles in Mexico would offer substantial climate benefits and yield direct fuel savings to end users, more than offsetting the incremental costs of vehicle efficiency technology.

List of Acronyms

ANPACT	National Association of Producers of Trucks and Buses (Mexico)
ARB	Air Resources Board (California)
BC	black carbon
COPERT	computer program to calculate emissions from road transport (European Commission model)
CO_2e	carbon dioxide-equivalent
DEF	diesel exhaust fluid
DPF	diesel particulate filter
EPA	Environmental Protection Agency (United States)
GDP	gross domestic product
GHG	greenhouse gas
GNI	gross national income
GWP-20 GWP-100	global warming potential over a 20- or 100-year time horizon
HD, HDV	heavy duty, heavy-duty vehicle
ICCT	International Council on Clean Transportation
INECC	National Institute of Ecology and Climate Change (Mexico)
IPCC	Intergovernmental Panel on Climate Change
IWGSCC	Interagency Working Group on Social Cost of Carbon (United States)
LEV	low emission vehicle
MOVES	motor vehicle emission simulator (EPA model)
$MtCO_2$	million metric tons of carbon dioxide
MY	model year
NOM	official Mexican standard
NO_x	oxides of nitrogen
OC	organic carbon
PM, $PM_{2.5}$	particulate matter, fine particulate matter with an aerodynamic diameter less than 25 micrometers
PPP GDP	gross domestic product at purchasing power parity
ppm	parts per million
SCC	social cost of carbon
SCR	selective catalytic reduction
SLCP	short-lived climate pollutants
TTW	tank to wheel
ULSD	ultra-low-sulfur diesel, with <15 ppm sulfur content
USD	United States dollars
VKT	vehicle-kilometers traveled
VSL	value of a statistical life
WTP	willingness to pay

References

ANPACT (2013). *Boletín Estadístico Mensual #253 Diciembre 2013*. Retrieved from http://anpact.com.mx/publicaciones/boletinANPACTdiciembre2013v7.pdf

Bureau of Labor Statistics (2014). CPI Inflation Calculator. United States. Retrieved July 9, 2014 from http://data.bls.gov/cgi-bin/cpicalc.pl?cost1=7.4&year1=2006&year2=2010

Blumberg, K., Posada, F., and Miller, J. (2014). Revising Mexico's NOM 044 standards: Considerations for decision-making. The International Council on Clean Transportation. Retrieved from http://www.theicct.org/revising-mexicos-nom-044-standards-considerations-decision-making

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S. K., Hopke, P. K., Jacobson, M. Z., Kaiser, J. W., Klimont, Z., Lohmann, U., Schwarz, J. P., Shindell, D., Storelvmo, T., Warren, S. G., & Zender, C. S. (2013). Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment. Journal of Geophysical Research: Atmospheres 118, no. 11 (June 16): 5380–5552.

Chambliss, S., Miller, J., Façanha, C., Minjares, R., & Blumberg, K. (2013). The Impact of Stringent Fuel and Vehicle Standards on Premature Mortality and Emissions. The International Council on Clean Transportation. Retrieved from http://theicct.org/global-health-roadmap

EIA (2014). Petroleum & Other Liquids. Diesel Fuel Release Date: May 5, 2014. Independent Statistics and Analysis, U.S. Energy and Information Administration, U.S. Department of Energy. Retrieved May 5, 2014 from http://www.eia.gov/petroleum/gasdiesel/

EPA (2000). Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Regulatory Impact Analysis. Environmental Protection Agency, Office of Air and Radiation. EPA420-R-00-026.

EPA (2010a). *User Guide for MOVES2010a*. Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency. Retrieved February 14, 2014 from http://www.epa.gov/otaq/models/moves/MOVES2010a/420b10036.pdf

EPA (2010b). Appendix B: Mortality Risk Valuation Estimates. *Guidelines for Preparing Economic Analyses*. December 2010. Retrieved from http://yosemite.epa.gov/EE%5Cepa%5Ceed.nsf/webpages/guidelines.html

EPA (2010c). Chapter 6: Discounting Future Benefits and Costs. *Guidelines for Preparing Economic Analyses*. December 2010. Retrieved from http://yosemite.epa.gov/EE%5Cepa%5Ceed.nsf/webpages/guidelines.html

EPA (2011). The Benefits and Costs of the Clean Air Act from 1990 to 2020. Office of Air and Radiation, U.S. Environmental Protection Agency. Retrieved from http://www.epa.gov/cleanairactbenefits/prospective2.html

EPA (2014). The Social Cost of Carbon. Retrieved June 18, 2014 from http://www.epa.gov/climatechange/EPAactivities/economics/scc.html

Goldman Sachs Economic Research (2007). Global Economics Paper No: 153. The Goldman Sachs Group, Inc. Retrieved from http://www.chicagobooth.edu/~/media/E60BDCEB6C5245E59B7ADA7C6B1B6F2B.pdf

Hammitt, J. K., and Robinson, L. A. (2011). The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations. *Journal of Benefit-Cost Analysis* 2 (1): Article 1.

Hart Energy and MathPro Inc. (2012). Technical and Economic Analysis of the Transition to Ultra-Low Sulfur Fuels in Brazil, China, India and Mexico. Prepared for the International Council on Clean Transportation. October 2012. Retrieved from http://www.theicct.org/technical-and-economic-analysis-transition-ultra-low-sulfur-fuels-brazil-china-india-and-mexico

He, J., & Wang, H. (2010). The value of statistical life: a contingent investigation in China. The World Bank. doi:10.1596/1813-9450-5421

TransportPolicy.net (2014). "Global Comparison: Heavy-Duty Emissions". The International Council on Clean Transportation & DieselNet. Retrieved from http://transportpolicy.net/index.php?title=Global_Comparison:_Heavy-duty_Emissions

INECC (2012). *VKT by vehicle age & Total sales 1993-2010*. Received February 13, 2014 from Iván Islas.

INECC (2013). *Ajuste para México con base en Kochi et.al., 2006 y Analytica*. Received June 6, 2013 from Verónica Garibay Bravo.

Integer (2014). DEF Tracker. Issue from April 2014. Retrieved May 9, 2014 from http://www.integer-research.com/environment-emissions/products/def-tracker/diesel-exhaust-fluid-def-price-tracker/

IWGSCC (2010). *Social Cost of Carbon for Regulatory Impact Analysis* (pp. 1–51). Interagency Working Group on Social Cost of Carbon, United States Government.

IWGSCC (2013). *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis*. Interagency Working Group on Social Cost of Carbon, United States Government. Retrieved from http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf

Miller, Joshua (2014). Timeline for implementation of nationwide emissions standards for diesel HDVs, 2014. The International Council on Clean Transportation. Retrieved from http://transportpolicy.net/index.php?title=Global_Comparison:_Heavy-duty_Emissions

Minjares, Ray; Wagner, David Vance; Baral, Anil; Chambliss, Sarah; Galarza, Sebastian; Posada, Francisco; Sharpe, Ben; Wu, Grace; Blumberg, Kate; Kamakate, Fanta; Lloyd, Alan; Kojima, Masami; Hamilton, Kirk; Johnson, Todd; Kopp, Andreas; Hosier, Richard; Akbar, Sameer (2014). *Reducing black carbon emissions from diesel vehicles: impacts, control strategies, and cost-benefit analysis*. Washington DC ; World Bank Group. http://documents.worldbank.org/curated/en/2014/04/19342185/reducing-black-carbon-emissions-diesel-vehicles-impacts-control-strategies-cost-benefit-analysis

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., and Zhang, H. (2013). Anthropogenic and Natural Radiative Forcing. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

OECD (2012). *Mortality Risk Valuation in Environment, Health and Transport Policies*. OECD Publishing. http://dx.doi.org/10.1787/9789264130807-en

OECD (2014). Dataset: Economic Outlook No 95 - May 2014—Long-term baseline projections. Retrieved May 21, 2014 at http://stats.oecd.org/Index.aspx?DataSetCode=EO95_LTB

Posada Sanchez, F. (2014). *Estimated Cost of Emission Reduction Technologies for Heavy-Duty Engines*. The International Council on Clean Transportation. Manuscript in preparation.

Posada Sanchez, F., Bandivadekar, A., & German, J. (2012). Estimated cost of emission reduction technologies for LDVs. The International Council on Clean Transportation. Retrieved from http://www.theicct.org/estimated-cost-emission-reduction-technologies-ldvs

PEMEX (2014). Monthly Petroleum Statistics. Retrieved May 9, 2014 from http://www.ri.pemex.com/files/dcpe/petro/epublico_ing.pdf

Stern, N., et al. (2006). Stern Review: The Economics of Climate Change, HM Treasury, London. Retrieved from http://www.hm-treasury.gov.uk/stern_review_report.htm

Stevens, G. A. (2008). *Environment and Health in Transition in Mexico: Risk Assessment and Economic Evaluation*. Harvard School of Public Health.

Tol, R. S. J. (2009). The Economic Effects of Climate Change. Journal of Economic Perspectives, 23 (2): 29–51.

Viscusi, W.K., & Aldy, J.E. (2003). The value of a statistical life: a critical review of market estimates throughout the world. Journal of Risk and Uncertainty 27: 5-76.

World Bank (2014). *World Bank Open Data*. Retrieved May 21, 2014 from http://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD