New Vehicle Fuel Economy and CO_2 Emission Standards Emissions Evaluation Guide

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für Internationale
Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the
Environment, Nature Conservation,
Building and Nuclear Safety

of the Federal Republic of Germany

Project Context

The Advancing Transport Climate Strategies (TraCS) project is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and funded through the International Climate Initiative of the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB).
Its objective is to enable policy makers in partner countries (Vietnam and Kenya) to specify the con-tribution of the transport sector to their respective Nationally Determined Contributions (NDCs). Detailed knowledge on transport-related emissions and mitigation potentials can furthermore lead to raising the level of ambition in the two countries.

The project follows a multi-level approach:
At the country level, TraCS supports (transport) ministries and other relevant authorities in systematically assessing GHG emissions in the transport sector and calculating emission reduction potentials through the development of scenarios.
At the international level, TraCS organises exchanges between implementing partners, technical experts, and donor organisations to enhance methodological coherence in emission quantification in the transport sector (South-South and South-North dialogue). The dialogue aims to increase international transparency regarding emissions mitigation potential and the harmonisation of methodological approaches in the transport sector. As part of this international dialogue, TraCS also develops knowledge products on emissions accounting methodologies.

The Guide

This guide on the calculation of emissions baselines of new vehicle fuel economy and CO_2 emission standards was developed by the International Council for Clean Transportation (ICCT) together with a Microsoft Excel based spreadsheet tool – the Fuel Economy Standards Evaluation Tool (FESET). FESET includes data of the Mexican new vehicle CO_2 emissions and fuel economy standards for 2012 to 2016, as an example. The tool is open so that values can be exchanged and adapted to allow applying the tool in other countries, too. Chapter 6 provides a step-by-step description of the Mexican example and how to apply the FESET.

Content

1. Description and characteristics of fuel economy standards for light-duty vehicles

Fuel economy (FE) or greenhouse gas (GHG) emission standards regulations are one of the main instruments available to policy-makers to achieve significant improvements in fuel consumption and GHG emissions from light-duty vehicles (LDVs). These standards require new LDVs to achieve lower fuel consumption and GHG emissions over time through continued development and application of fuel efficient technologies. Adoption of such standards results in a market transformation towards vehicles that are increasingly fuel-efficient-consuming less fuel per kilometre driven and thus emitting less GHG.

New GHG emission and FE standards regulations are policies typically set at the national level and typically span three to eight years. Additional regulatory phases are commonly applied to continue these policies. Successful implementation of new vehicle GHG/FE standards translates into more efficient vehicles being incorporated into the fleet, which, combined with the natural retirement of older and less efficient models, results in an improvement of the national fleet average fuel efficiency.

The regulated entities are vehicle manufacturers and importers of all new vehicles intended for sale within the country. Each automotive manufacturer should meet a target value based on the LDV fleet that it sells. Each manufacturer's compliance with their target ensures that the entire national fleet of new vehicles achieves the desired reductions in GHG emissions and fuel use. FE/GHG standards mandate no specific technology, fuel, or vehicle type/size. Manufacturers can choose the technology pathway that is most suitable to their business plan while respecting local consumer preferences.

Globally, the application of stringent GHG/FE standards in key regions is expected to attenuate and even offset growth in vehicle activity and vehicle sales numbers by reducing overall GHG emissions from the transportation sector. Figure 1 shows the evolution of sales weighted carbon dioxide (CO_2) emissions from the passenger car fleets of ten countries with GHG or FE standards in place today (Yang, 2017). The figure compares country standards for passenger vehicles in terms of grams of CO_2-equivalent per kilometer adjusted to the European NEDC test cycle. The European Union has historically outpaced the world with the lowest fleet average target of 95 gCO_2/km by 2021. However, South Korea will match, if not exceed the European Union with a fleet target of 97 gCO_2/km in 2020. With high hybrid percentage, Japan already reached its 2015 target of 142 g/km in 2011 and 2020 target of 122 g/km in 2013. If Japan keeps reducing CO_2 emissions at this same rate, Japan's passenger vehicle fleet would achieve 82 g/km in 2020, far below the targets set by other countries. The United States and Canada, long laggard in regulating fuel economy, have evolved into leaders. As the first country with 2025 targets, the example set by U.S. has encouraged other countries (e.g., Canada) to consider enacting similarly long-term standards. The United States is expected to achieve the greatest absolute GHG emission reduction – 49% – from 2010 to 2025. [1]

[1] China proposed a fleet average fuel consumption of 4 L/100km by 2025 (MIIT, 2015), which would be among the lowest target levels if it is enacted.

Figure 1: Passenger car sales CO_2 emission targets and sales-weighted averaged actual fleet historical performance[2]

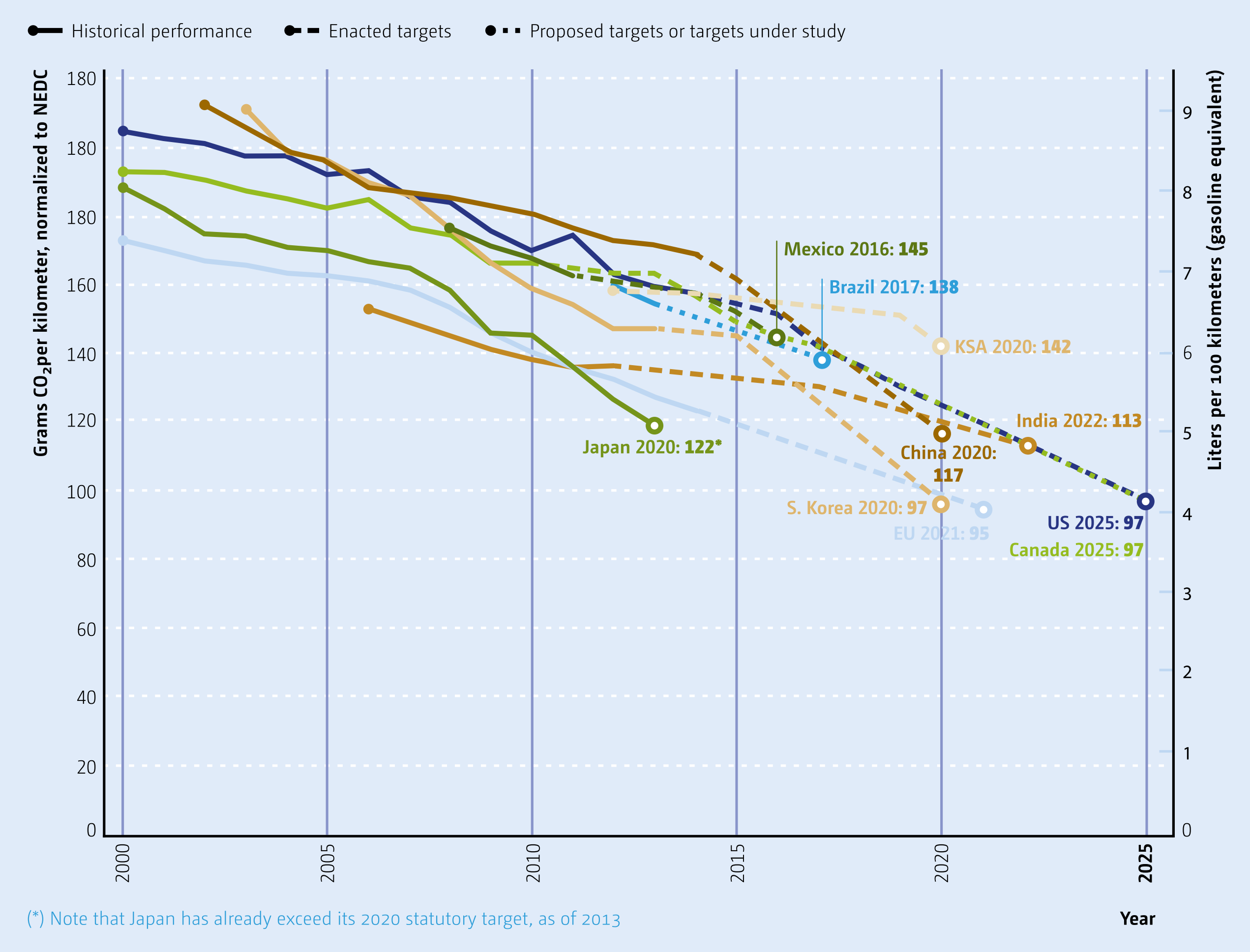
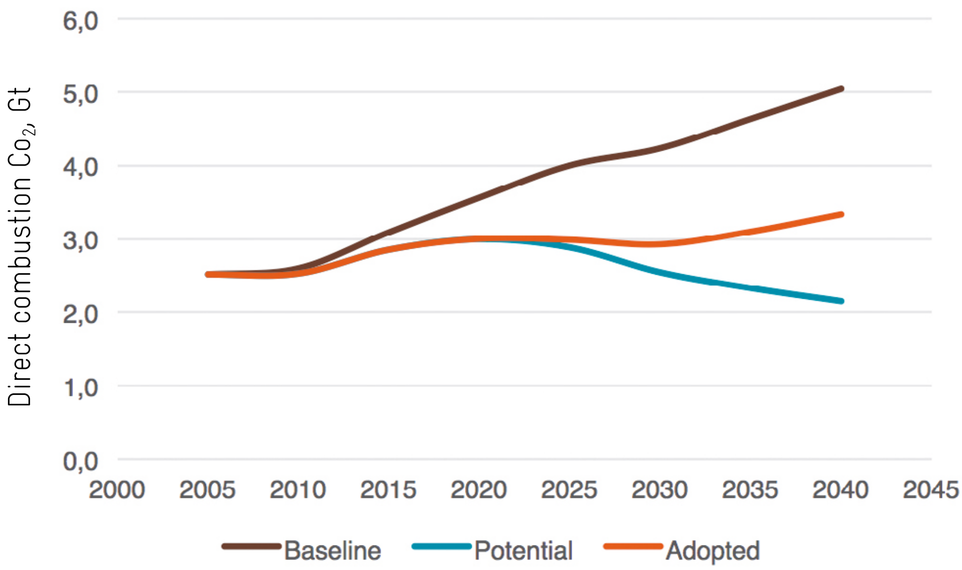


Figure 2 presents an example of the overall impact of FE/CO_2 standards adoption for light-duty vehicles in selected G20 countries (Miller, Du, and Kodjak, 2017). Three scenarios are compared for new vehicle efficiency and CO_2 standards: the "baseline" scenario assumes no further improvements in new vehicle efficiency after 2005, to enable the estimation of benefits from adopted policies. The "adopted policies" scenario includes all policies adopted as of September 2016, including those taking effect in the future. Finally, the "world-class" scenario models the impacts of all countries developing new vehicle efficiency standards consistent with the objectives of the G20 Energy Efficiency Leading Program (EELP): these aspirational targets include a 50% reduction in LDV fuel consumption compared to a 2005 base year by 2030 (G20, 2016). The analysis by Miller, Du and Kodjak show that currently adopted vehicle efficiency standards will avoid 1.7 billion tons of carbon dioxide ($GtCO_2$) in 2040, whereas new world-class LDV efficiency standards could mitigate direct emissions from fuel combustion by an additional 1.2 $GtCO_2$ in 2040.

[2] International Council on Clean Transportation (ICCT) 2016. Global PV Standard Library. Available at: http://www.theicct.org/global-pv-standards-chart-library

Figure 2 Direct combustion CO_2 emissions of light-duty vehicles in selected G20 member states under baseline, adopted policies, and world-class efficiency scenarios, 2005–2040.

Figure shows historical and projected emissions for Australia, Brazil, Canada, China, the EU-28 (including United Kingdom), India, Japan, Mexico, the United States, and Russia. Source: Miller, Du, and Kodjak (2017)



Vehicle fuel economy and equivalent metrics

Different metrics can be used to describe the amount of fuel, energy and GHG emissions generated by unit of distance traveled by a vehicle. Selection of the metric is driven by the intention of the policy to either reduce fuel use, or GHG emissions.

Fuel economy (FE) measures distance traveled per unit of fuel consumed. The most common metrics are kilometers per liter (km/L) and miles per gallon (mpg) in the U.S.

Fuel consumption (FC) is the reciprocal of fuel economy, and measures fuel consumed per distance traveled. It is usually expressed in liters per 100 kilometers (L/100 km), and it is used in Europe, for example.

HG/CO_2 emissions measures GHG or CO_2 emissions per distance traveled, expressed as grams of pollutant per kilometer or mile. The metric can be expressed in grams of CO_2 or CO_2-equivalent per unit distance (gCO_2/km or gCO_2e/km). A CO_2-equivalent (CO_2e) metric incorporates emissions of non-CO_2 pollutants, using the global warming potential (GWP) to translate their impact to CO_2 equivalency. Primary GHGs besides CO_2 are methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases).

Energy consumption (EC) measures the energy consumed per distance traveled, for example in megajoules per kilometer (MJ/km). Despite being a less common metric, it is relevant as a fuel-neutral metric across different fuel types and vehicle technologies. Vehicle energy consumption is the metric used in Brazil's vehicle efficiency standards policy.

2. Structure of mitigation effects

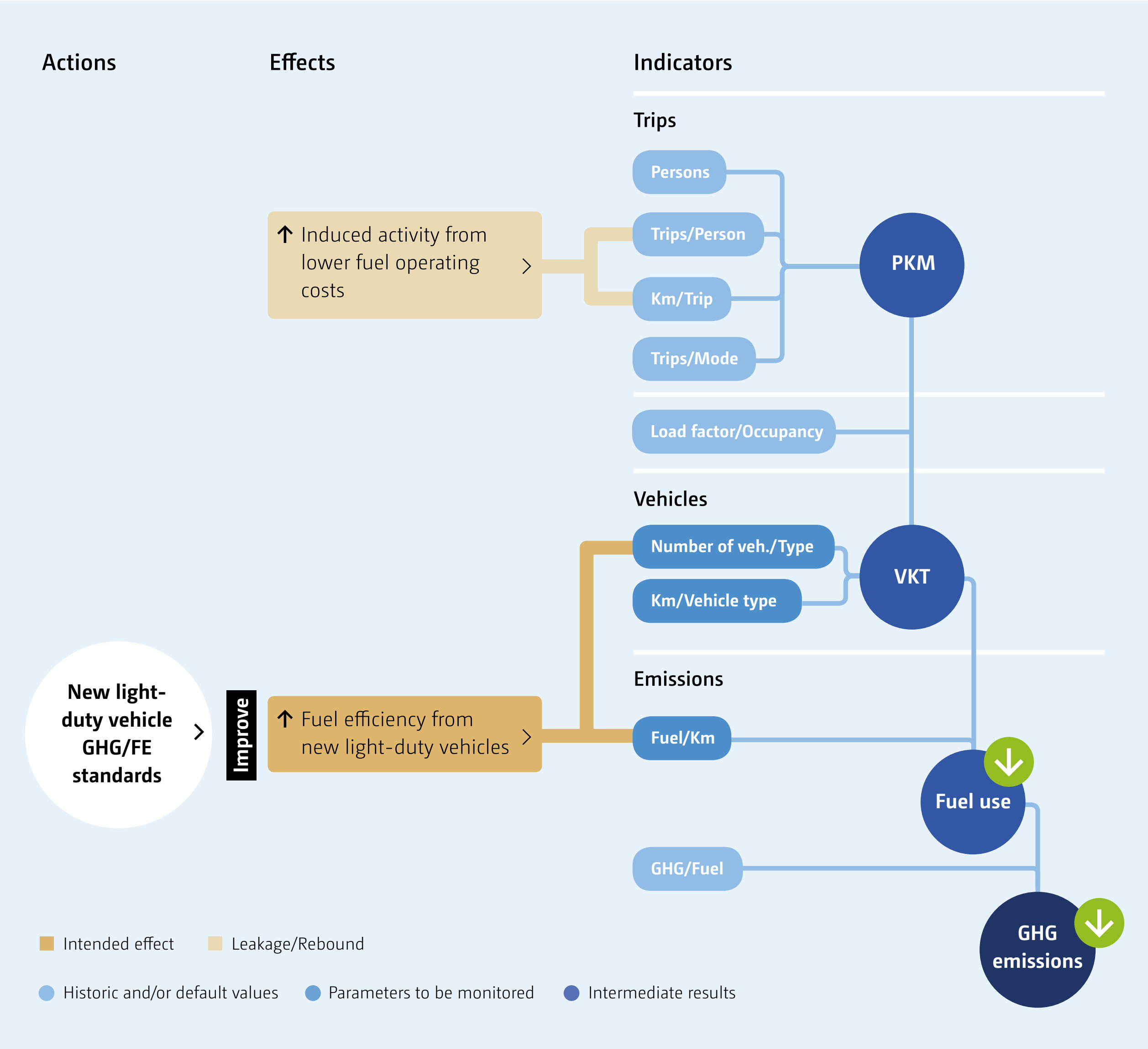
2.1 Cause impact chain

Adoption of new vehicle GHG/FE standards measurably reduces GHG emissions and fuel consumption for the average light-duty vehicle via increased adoption of fuel efficient technologies. This improvement, coupled with new vehicle sales and activity–which have been showing significant growth in most emerging economies (ORNL, 2016)–has the potential to significantly reduce fleetwide GHG emissions compared to business-as-usual (BAU) conditions. Those reductions can be assessed applying bottom-up models based on CO_2 emission factors, number of vehicles, and vehicle activity. This measurable fuel consumption and GHG reduction found in regulated average new vehicles would reduce the overall vehicle fleet GHG impact as illustrated in Figure 3.

Adopting new vehicle GHG/FE standards regulations would provide the following direct and indirect benefits with respect to the baseline scenario:

- Reduce the fleet average emission of CO_2 and fuel consumed per kilometer driven for the fleet covered.
- Reduce the total annual contribution of GHG emissions from the transportation sector.
- Reduce fuel consumption from the transportation sector, and, potentially, fuel imports.
- Reduce emissions of GHG and pollutants generated by oil extraction, fuel production, and distribution.
- Accelerate adoption of advanced efficiency technologies and potentially incentivize transition to electric mobility and zero emissions. As the standards become more stringent over time, the most advanced fuel-efficient technologies are required. Estimates by EPA in the US show that the most stringent GHG/FE standards in 2025 would require increased adoption of hybrid and battery electric vehicles to meet future standards (USEPA, 2016). Other complementary policy instruments can be deployed to increase the rate of adoption via direct taxation incentives or indirect incentives such as easier access to high occupancy lanes or parking spots.

Figure 3 – Causal chain for new vehicle fuel economy and greenhouse gas emission standards



2.2 Key variables to be monitored

GHG/FE standards require vehicle manufacturers to achieve a GHG emissions or fuel economy target level in a given year. Applying the regulations to a reduced set of stakeholders rather than individual consumers ensures compliance and simplifies enforcement of the standards. Thus, the key variable to be monitored when designing and implementing a new vehicle GHG/FE standard is the performance of each manufacturer with respect to its target. As GHG/FE standard targets become more stringent over time, monitoring is required on an annual basis. Other variables that affect the actual GHG emissions of the transportation sector are new vehicle sales volume and vehicle activity.

Monitor for intended effects:
New Vehicle GHG or FE Standards
Under a new vehicle GHG or FE standard, each automotive manufacturer has a GHG/FE target value for its light-duty vehicle fleet sold into the market for a given year. Targets can be designed in two ways: as manufacturer fleet average target values (also known as corporate average) or as individual (per-vehicle) minimum efficiency target values.[3] Fleet-average targets incentivize the manufacturer to offer very efficient models to balance out the less efficient ones. Fleet averaging offers flexibility to manufacturers to reach their respective targets, thereby facilitating setting strong targets. And because they provide an incentive for technology to keep improving, fleet-average targets ease the process of increasing standard

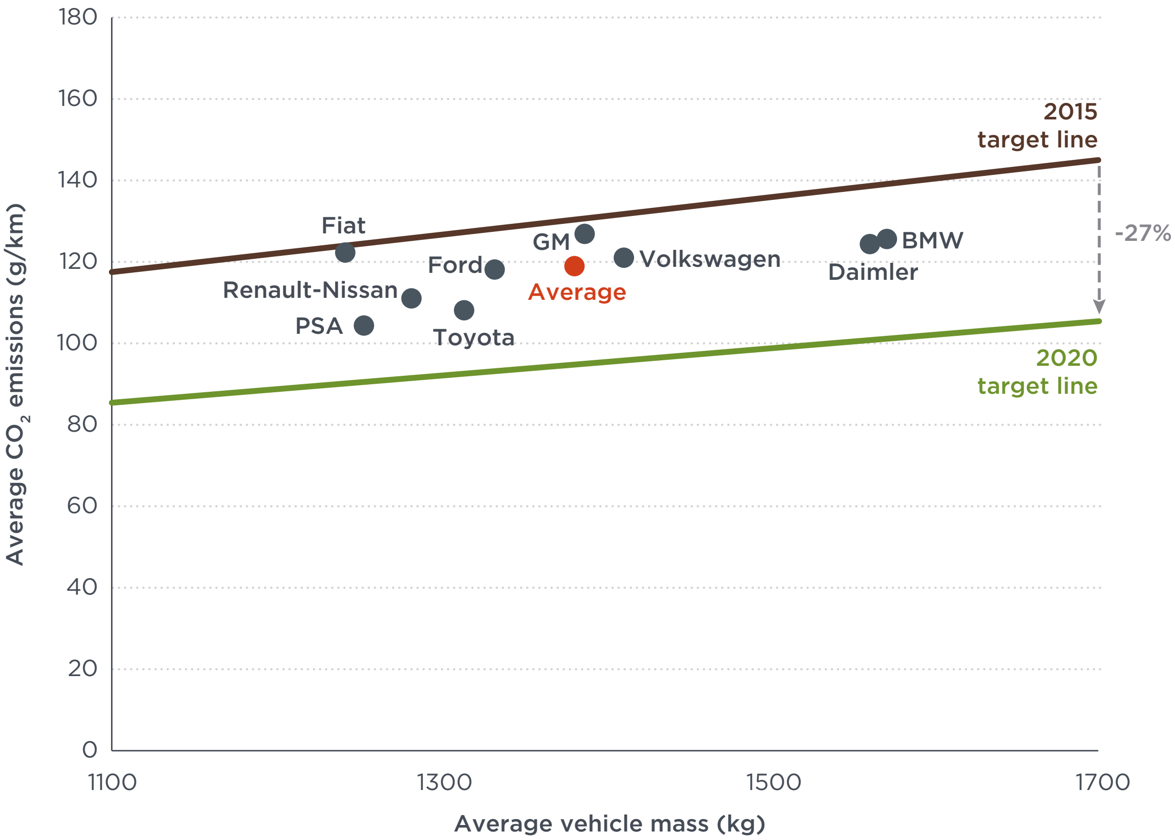
[3] As an example, the first two phases of the Chinese passenger car fuel consumption standards regulation (2005–2006 and 2008–2009) used a per-vehicle minimum efficiency performance approach. The intention of the Ministry of Environmental Protection (MEP) was to force a quick phasing out of older vehicle technology. While this can be a useful approach for GHG/FE standards, this document is intended to support best practices to reduce fuel consumption and GHG emissions from new vehicles, and therefore the text focuses on a sales-weighted regulatory design.

stringency over time. Per-vehicle minimum efficiency targets restrict the sale of models that have fuel consumption above some level; they are restrictive to manufacturers but are easier to implement and monitor. Due to the restrictive nature of this design, per-vehicle targets are required to be less stringent compared to average targets to avoid imposing bans on a wide range of models. Such standards also offer a limited incentive for further investment in efficiency technology development. Most countries with regulated vehicle fleets have adopted fleet average standards designs – as shown in Figure 1. Saudi Arabia's FE program design is an interesting example in that it applies fleet average targets for new vehicle sales and per vehicle maximum targets for its used import vehicle sales (SASO, 2015).

Each target is designed as a linear function of vehicle footprint[4] or vehicle weight, with less stringent targets for larger or heavier vehicles. Using these metrics helps to specifically target vehicle efficiency technologies and avoid impacting consumer choices and manufacturer competitiveness. The targets may be expressed in grams of CO_2 or CO_2-equivalent per unit distance (gCO_2/km or gCO_2e/km), distance driven per litre of fuel consumed (km/L), energy per unit distance (MJ/km), or fuel consumed for certain distance (L/100km).
The targets are tightened over time. The rate of annual target improvement ranges between 3.5% to 6.0%. Annually increasing the stringency of the target results in a fleet that becomes more efficient each year as new targets are set and new (more efficient) vehicles are phased in to meet them. While the new vehicle fleet average efficiency improves annually, older and less efficient vehicles are retired from the fleet, improving the overall vehicle stock fleet average fuel efficiency.

An example comparison of the CO_2 targets for Europe and the performance of each automotive manufacturer is shown in Figure 4. The horizontal axis shows vehicle weight as the reference parameter and the vertical axis shows CO_2 values. Lines show targets and dots show the actual CO_2 performance of each manufacturer in 2015. The data for each manufacturer is based on a dataset provided by the European Environment Agency (EEA) that monitors CO_2 emissions from new passenger cars in the EU (EEA, 2016). The EEA data show that the mandatory emission reduction target set by the EU legislation for 2015 was met on average. New cars sold in the EU in 2015 had average CO_2 emissions of 119.6 g CO_2 /km, which was 8% below the 2015 target, and 3% lower than in 2014. All major manufacturer groups met their mandatory CO_2 emission limits in 2015. For each manufacturer group, the 2020/21 target implies a decrease of approximately 27% in average CO_2 emissions compared to the 2015 target (ICCT, 2016).

Figure 4 – Performance of the top selling EU passenger car manufacturer groups for 2015, along with 2015 and 2020/21 CO_2 emission target lines.
Source: ICCT (2016)



4 The footprint of a vehicle is defined as the area circumscribed by the vehicle's wheelbase and average track width (i.e., footprint equals wheelbase times average track width).

Number of vehicles

The number of new vehicles entering the fleet each year (i.e., new vehicle sales) is used as an input to calculate the total new vehicle fleet contribution to GHG emissions and fuel consumption. Individual manufacturer new vehicle sales are also used as inputs to calculate performance with respect to the GHG/FE targets and to determine compliance with the standards. It should be noted that new vehicle fuel economy standards do not regulate the number of vehicles sold.

Monitoring the current vehicle fleet size (or vehicle stock), via national vehicle registration data or other sources, is required to provide absolute GHG emissions and fuel consumption by the baseline fleet; it is also needed for calculating the relative impact of the intended action. Vehicle retirement rates are needed to estimate the outflow of vehicles from the vehicle stock and to provide an estimate of the current vehicle stock. Vehicle retirement rates are mathematical functions that describe the probability of finding a vehicle operating after certain age. A new vehicle is much more likely to be found operating (and contributing to the GHG inventory) after year one of entering the fleet than a vehicle that entered the fleet 30 years ago.

Vehicle activity

Vehicle activity, in kilometres traveled per vehicle per year or VKT, is used as an input for calculating total fleet fuel consumption and GHG emissions. Typically, the input comes as an average value by vehicle type (e.g., light-duty, heavy-duty, urban buses, taxis) from national statistical data from national road or transit authorities. This input does not require active monitoring as part of the standard design or Monitoring & Reporting ex-ante and ex-post activities, but it is recommended to observe official or academic publications for significant changes on fleet average VKT values. VKT also changes with vehicle age; VKT degradation curves can be developed to account for that, or can be adopted from similar markets.

One known negative indirect effect of new vehicle GHG/FE standards for light-duty vehicles is the potential increase in vehicle activity due to drivers experiencing lower fuel consumption and corresponding lower driving operating cost. This is known as rebound effect. The rebound effect for the transport sector has been estimated to be between 3% and 18% for passenger vehicles in the US (US EPA, 2015) and globally it has been estimated to be between 10–30% for road transport (Lah, 2015; Fulton et al., 2013). The numerical interpretation corresponds to that of an elasticity: assuming a rebound effect of 10%, the impact of 25% improvement in fuel efficiency would be a 2.5% increase in VKT (i.e., the 10% of 25%). The literature also concludes that the rebound effect declines over time as population incomes rises (US EPA 2015).

2.3 Interaction Factors

The most important factors affecting the magnitude of the fuel consumed and GHG emitted by the fleet are the design of the GHG/FE standards, and the extent and activity of the vehicle fleet. Table 1 presents a summary of those factors and GHG effects.

Table 1– Factors that affect key GHG/FE standards variables

Factor	Changes	Reasons for the change and effects on total GHG
GHG/FE regulatory design	GHG target design and rate of annual improvement	More stringent GHG targets with higher annual improvement rates would result in lower total GHG emission reductions. Ambitious GHG targets and annual rates of GHG improvement would have to be evaluated against a realistic assessment of the ability of the regulated party to achieve the targets via available technologies and costs.
Vehicle activity	VKT changes due to rebound effect	Lower fuel operating costs due to more efficient vehicles may incentivize the consumer towards higher vehicle activity. This would offset to various degrees the reduction of total GHG emission from new vehicle efficiency improvements.
Fleet size	Increase in the number of vehicles in the fleet	Rapidly growing vehicle markets will face more difficult challenges reducing the total GHG emissions than more saturated markets, but effective regulations will lead to bigger GHG reductions compare to BAU. GHG/FE Standards are not designed to affect vehicle sales. Other policy instruments, such as vehicle taxes can have an impact on fleet growth and replacement rates. In regions where imports of used vehicles are significant compared to new vehicle sales the impact of those vehicles on total GHG emissions has to be estimated.

2.4 Boundary setting

The boundary setting of MRV on GHG/FE standards is closely linked to the regulatory scope. GHG/FE standards are defined as national or regional regulations. The technical scope of the regulation calls for defining what type of vehicles would be covered under the standard and for how long. The regulatory target and the impacts on sustainability are also included as part of the boundary definition.

Geographic boundary
As a vehicle sale occurs at the national level, the geographic boundary is at that level, under a national policy. It is acknowledged that local policy measures that complement national GHG/FE standard regulations–in particular compact city planning and the provision of low-carbon transport modal alternatives, such as public transport, walking, and cycling, are a vital component of a low-carbon transport strategy.

Vehicle types
The common practice is to develop light-duty vehicle fuel economy or GHG emissions standards regulations independent of other vehicle types. Light duty vehicle standards can be developed with independent targets for passenger cars and for other larger vehicles like pick-up trucks and SUVs, as done in the US. Another option is to have independent regulations for passenger cars and for light commercial vehicles, as implemented in Europe.
To clarify the scope of the FE/GHG standards across regions, this section provides examples of definitions of passenger car and light truck/commercial vehicle in some regions. The definitions are different in maximum gross vehicle weight (GVW) and seat requirement, but generally fall into two groups. For passenger cars, the maximum GVW is 3,856 kg in the United States, Canada, Mexico, and Brazil, whereas the maximum GVW is 3,500 kg in the European Union, China, India, Japan, Saudi Arabia, and South Korea. Light truck is the term commonly used in the United States, Canada, and Mexico, whereas light commercial vehicle (LCV) is used in other regions. The GVW cap for cargo/commercial vehicles is the same as for passenger cars in each region. In addition to cargo vehicles, the United States and Canada categorize four-wheel drive SUVs and passenger vans up to 4,536 kg as light trucks, and China also regulates passenger vehicles with more than 9 seats in its LCV standards. Note that the same vehicles may be categorized differently in different regions. For example, four-wheel drive SUVs are registered as light trucks in the United States and would likely be registered as passenger cars in the European Union because they are used for private purposes. It is necessary to be mindful of these categorization differences when defining the scope and, more importantly, when designing the targets and calculating actual performances.

For other vehicle types, such as heavy-duty vehicles, separate GHG/FE standard regulations with different design elements could be conceived. The regulation of heavy-duty vehicles, which span over a wider range of vehicle types, uses, and drive cycles (e.g., long-haul trucks, refuse trucks, delivery trucks), requires a very different approach and different technology packages are available for different vehicle types and uses.

Ultimately, the decision on sectorial boundaries depends on the country-specific vehicle class definitions as defined by national Ministries/Departments of Transport or Industry.

Time scale boundary
The temporal boundary of baseline determination for monitoring and reporting should go beyond the regulatory implementation timeline. The regulatory implementation typically covers 3 to 8 year periods, typically with the intent to continue progress in reduction of GHG emission over subsequent regulatory phases. Figure 1 provides an idea of the time scale for regulatory implementation in several countries. On the other hand, the analysis of the effect of the regulation on GHG emissions and fuel consumed should cover a longer timeframe as the useful life of vehicle is 20 to 30 years and the peak benefit of standards adoption on GHG emissions is reached around 10–15 years into the program (once the older inefficient fleet is retired). Thus, for monitoring and reporting work on new-vehicle GHG/FE standards, a longer boundary is needed to capture the long-term effects of this type of mitigation action, between 30 to 40 years beyond the final year of regulatory adoption (e.g., if the GHG standard covers new vehicles sold between 2020 and 2030 then the evaluation should cover until 2060 at a minimum).

Regulatory Target
Table 2 provides an overview of the passenger vehicle CO_2 emission standards currently in place (Yang, 2017a). As can be seen from the table, countries chose different metrics for regulating, including CO_2 or GHG emissions and fuel consumption or fuel economy. The choice for an underlying metric is usually based on specific objectives of the regulations and also on historical preferences. Despite these differences in metrics, all of the standards in place address the same issue, expressed as reducing vehicle CO_2 emissions for the purpose of this paper. Note that the targets in the table are provided as per the fuel economy test procedure, which differs from the harmonized value shown in Figure 1. [5]

[5] A comparison of the most important vehicle fuel economy test procedures, their impacts on fuel consumption and CO_2 emissions, and a description of the methodologies to translate results between test procedures is available in the report by Kühlwein, German & Bandivadekar (2014).

Table 2 – Overview of current new passenger car CO_2 emission standards. Adapted from Yang (2017a)

Country	Global Market share	Target year	Metric	Target value	Parameter	Test procedures
China	30%	2015 & 2020	FC	6.9 L/100km & 5.0 L/100km	Weight	NEDC
EU	20%	2015 & 2021	CO_2	130 gCO_2/km & 95 gCO_2/km	Weight	NEDC
U.S.	12%	2016 & 2025	FE/GHG	36.2 mpg or 225 gCO_2/mi & 56.2 mpg or 143 gCO_2/mi	Footprint	U.S. combined
Japan	7%	2015 & 2020	FE	16.8 km/L & 20.3 km/L	Weight	JC08
India	4%	2016 & 2021	CO_2	130 g/km & 113 g/km	Weight	NEDC
Brazil	4%	2017	EC	1.82 MJ/km	Weight	U.S. combined
South Korea	2%	2015 & 2020	FE/GHG	17 km/L or 140 gCO_2/km & 24 km/L or 97 gCO_2/km	Weight	U.S. combined
Canada	1%	2016 & 2025	GHG	217 gCO_2/mi – est & 143 g/mi – est	Footprint	U.S. combined
Mexico	1%	2016	FE/GHG	39.3 mpg or 140 g/km	Footprint	U.S. combined
Saudi Arabia	1%	2020	FE	17 km/L	Footprint	U.S. combined

Notes: FC = fuel consumption, FE = fuel economy, EC = Energy consumption est: estimated value, g/mi = grams per mile, mpg = miles per gallon, MJ/km = megajoule per kilometre

Sustainability effects

The main effects of adopting GHG/FE standards are, in general terms, reduction of the LDV fleet fuel consumption and a consequent reduction of CO_2 emissions. Depending on the regulatory target design, these standards can bring additional benefits if the target design involves tailpipe emissions of CH4, N2O, and black carbon, and if the regulatory design contained provisions for addressing automobile air conditioning refrigerant systems leaks, which traditionally use fluorinated gases as the working fluid and have large global warming potential values.

A secondary benefit is reduction of upstream emissions of black carbon, NOx and SOx and other pollutants and toxics that are generated from supplying fuels to on-road transport (US EPA, 2012). Upstream emissions from gasoline, diesel and CNG production cover: domestic crude oil production and transport, petroleum production and refining emissions, production of energy for refinery use, and fuel transport, storage and distribution.

In summary, the boundaries, scope and targets for new-vehicle GHG/FE standards are as follows (Table 3):

Table 3 – Summary of main MRV design elements for new-vehicle GHG/FE standards

Dimension	Options for boundary setting
Geographic boundary	National or regional level regulation. (Large states have also effectively regulated passenger vehicle GHG emissions, but federal regulations are more common.)
Sectorial boundary	Depending on vehicle classification pertaining to the regulation, the MRV system would cover manufacturers and importers of new passenger cars and/or light-commercial vehicles/light trucks for sale in the country.
Temporal Boundary	GHG/FE standards policy enforcement: 3–20 years. It can be split into 3–5 year phases with interim reviews between phases. Ex-ante assessment of policy proposal should consider a longer timeframe as the benefits reach peak values around 15 years after the end of the last regulatory period.
Regulatory target	Main target: CO_2 emissions and/or fuel consumption or equivalent metric. Secondary targets: CH4, N2O and F-gas[6] emissions
Sustainability effects	Reduced fuel consumption and improved energy security. Upstream emissions of black carbon, NOx and SOx in countries that refine petroleum or other fossil fuels into automotive fuels.

2.5 Key methodological issues

The main issues for quantifying GHG emission reductions are related to data availability and defining some key assumptions for the inventory model. Markets that allow used vehicle imports introduce challenges with respect to defining vehicle stock and retirement rates.

Optimal versus real data availability

Optimal monitoring and reporting methodology could be applied in countries with complete, updated, and reliable statistical and economic data. This covers vehicle databases with sales and FE/CO_2 emissions values, and updated values for vehicle activity and stock. The data would ideally be sourced from credible stakeholders, especially vehicle sales and performance data. Modeling assumptions can be better tailored in countries where the economic indicators used for defining key values such as vehicle sales growth can be properly sourced. In most study cases, part of the data may be outdated or unavailable and alternative sources have to be used to fill in the blanks. In some study cases, vehicle data, sales and FE/CO_2 values, are not available or the source of the latter is unknown (e.g., no information on test cycle used). Vehicle activity data is somewhat available, but VKT degradation curves are not and may require using other country's curves. Vehicle stock is typically available from international vehicle organizations but the time span is very short; vehicle retirement curves can be adjusted to reflect the local data available. Table 4 provides a list of optimum data required and alternatives to develop the new vehicle FE/CO_2 baseline value and study the standard benefits (BAU vs. Regulation).

[6] Fluorinated gases used as air conditioning refrigerants have a broad range of GWPs.

Table 4 Data inputs required for developong a vehicle CO_2/FE baseline

Database level	Optimum	Alternatives
Data for new vehicle sales weighted FE/GHG baseline		
GHG/ FE data	Model by model official test cycle GHG/FE data Official sources: Manufacturer association (MA) or government homologation body	Unofficial test cycle GHG/FE data Introduces uncertainties for calculating sales weighted average values Unofficial sources: Vehicle market data vendors (e.g., POLK, ADK)
Sales data	Model by model sales data. Sales data should ideally be provided on a model by model basis Official: Manufacturer association data or government body (department/ministry of transport, industry or treasury)	Aggregated sales data by manufacturer. Aggregated sales data introduces uncertainties for calculating sales weighted average values Unofficial: data vendors
Vehicle characteristics	Model by model engine displacement, fuel used, weight, wheelbase, footprint, and other characteristics Sources: data vendors or manufacturer websites	High priority data are: vehicle dimensions (wheelbase, width, length) and weight. Other characteristics are lower priority. Sources: data vendors or manufacturer websites
Data for GHG emissions benefits analysis		
Vehicle stock	Official national vehicle registration data for a period of years Sources are Ministry of Transport or local transit agencies	Regional data can be used and extrapolated to national based on population indicators
Fuel use [Needed to validate GHG fleet emissions calculation with real fuel use]	Official national annual fuel consumption, by fuel type Sources are Ministry of Transport or Ministry of energy or Oil	Regional extrapolated
Vehicle growth projections	Official national vehicle growth projections from Ministry of Transport or Economy	Estimated based on local economic indicators such as expected GDP growth and population growth
Vehicle activity	Official vehicle activity data from Ministry of Transport or local studies by local research bodies	Estimated from other vehicle markets with similar characteristics.
Vehicle retirement curves	Official vehicle retirement curves. This can be calibrated with local stock fleet data	Estimated from other vehicle markets with similar characteristics.

In summary, the MRV design process should consider the following challenges:

- Data availability on new-vehicle CO_2 emissions or fuel economy for all new models sold in the market in a given year.
- Data availability on new-vehicle sales, and as granular as possible, i.e., model-by-model basis.
- Data availability on key technology elements of models sold in the market, such as fuel type, vehicle size and weight, engine size, and others.
- Data availability on vehicle stock, which usually comes from annual vehicle registration data.
- Availability of national curves for vehicle retirement rate and national VKT deterioration curves by vehicle age.
- Vehicle sales growth assumptions based on economic activity indicators that can change due to global market fluctuations.
- Data availability on FE and sales for used vehicle imports in markets that allow it.

2.6 FE/GHG Standard complementary policies

New vehicle GHG and fuel economy standard regulations are designed to incentivize manufacturers to offer the most technologically efficient vehicles in the market. Policies and programs designed to incentivize the demand of more efficient vehicles are important complementary measures to take into consideration and action. The main complementary policies/programs are:

- New vehicle fuel economy and/or CO_2 labeling programs. Labeling programs inform the consumer about the efficiency of the vehicle, potentially influencing the decision to purchase a more efficient one. Labeling programs that include information on annual fuel costs can help relate policy impacts to consumer decisions.
- Fiscal incentives linked to fuel efficiency. Fiscal incentives can be designed to influence consumer choice by attaching larger fiscal loads to the least efficient vehicle models. By providing consumers with additional incentives to choose the more efficient models overall, fiscal incentives can both assist manufacturers in meeting regulatory targets and assist regulators in achieving sector targets. Incentives can be designed as taxes, fees and rebates, and can be linked to different fiscal instruments including import taxes or fees, registration fees, annual operating fees or taxes, or toll roads. The reader should be made aware of two tools, Fuel Economy Policies Implementation Tool (FEPIT) developed by the International Energy Agency, and the ICCT's Feebate Simulation Tool, to estimate the impact of fiscal policies, and other policy instruments, on average fuel economy values of new passenger vehicles. Fiscal policies addressed by FEPIT are registration, circulation and fuel taxes[7]. The ICCT's Feebate tool focuses on design of CO_2-based taxation programs for vehicles.[8]

GHG and fuel consumption reductions from the adoption of label programs and the standards are measured by new vehicle sales and their efficiency, which come from a single source: manufacturer's reports to regulators. To avoid double counting benefits, some level of coordination between the managers of each program (standards, label and taxes) is required. Coordination can be aimed at identifying what achieved GHG benefits can be assigned to each program and how to report it for MRV purposes.

Other policies that affect key variables defining total GHG emissions from LDVs but that are out of the scope of this type of mitigation are fuel prices and fuel taxation policies. Fuel prices can change due to crude oil market price changes, and due to national or regional fuel taxation policy changes. Fuel price variations may influence not only consumer decisions on new vehicle purchases, but also manufacturers' product planning, inducing an impact in actual (ex-post) new vehicle sales-weighted fleet average fuel economy values. Fuel price variations my also affect overall fleet size and activity; factors that contribute to total GHG and fuel consumption. Fuel price effects on total GHG emissions and fuel consumption are specifically addressed in the Passenger and Freight Transport Volume of the Compendium on GHG Baseline and Monitoring – Mitigation Action type 8. Pricing Policies (Eichhorst et al., 2017).

[7] International Energy Efficiency (IEA) Fuel Economy Policies Implementation Tool (FEPIT) Available at: http://www.iea.org/topics/transport/subtopics/globalfueleconomyinitiativegfei/fepit/
[8] International Council on Clean Transportation (ICCT). Feebate Simulation Tool. Available at: http://www.theicct.org/feebate-simulation-tool

3. Determining the baseline and calculating emission reductions

3.1 Analysis approach

Developing the baseline scenario annual contribution of GHG emissions from the light-duty vehicle fleet and calculating the emission reductions due to GHG/FE standards implementation involves two main activities:

1. Calculating the fleet average GHG emissions of new vehicles for a baseline year, and,
2. developing a model to calculate and compare fleet wide GHG emission and fuel consumption under a BAU scenario and an intervention or regulated scenario.

Both the ex-ante and ex-post analyses share some of the inputs, but ex-post analysis can make use of actual vehicle fleet changes in terms of new vehicle fleet average CO_2 values and sales numbers. Ensuring real-world FE and GHG emissions performance of the new fleet and estimating the corresponding impact on total GHG emitted, would require a dedicated study that can be can envisioned and designed in the early stages of policy and/or MRV development.

3.1.1 Determination of baseline new-vehicle fleet-average GHG emissions

The objective of this first step is to have a precise evaluation of the fleet-average FE and GHG emissions generated by the new-vehicle fleet that is entering the national market during a given year or period of evaluation (model year or fiscal year). The main output of this step is a pair of values: the first one is the new-vehicle fleet-average FE or GHG emissions value (gCO_2/km or equivalent metric); and the second one is the new vehicle fleet average reference parameter, either vehicle mass or vehicle size, used to define the target. The new vehicle fleet average CO_2 emissions value is calculated as sales-weighted average CO_2 emissions, in g/km, or equivalent metric; it represents the average CO_2 emissions rate, or efficiency, of all new vehicles entering the fleet during a set time, i.e., the baseline year. The reference parameter typically used is either sales-weighted fleet average mass (in kg) or the sales-weighted fleet average footprint (in m^2).

Calculating the fleet sales weighted average GHG/FE requires two main sources of data:

- Model-by-model certification values for CO_2 emissions, or fuel economy, or fuel consumption, and reference parameter data (vehicle weight or footprint), and
- Model-by-model sales data during defined the regulatory cycle (calendar year, fiscal year, or model year)

Ideally, model-by-model certification data on CO_2 (or fuel economy), vehicle parameters, and sales would come from the same source, either a government institution or an industry source. In cases where part of the data is not available there are options to supplement the data, albeit at the cost of introducing uncertainties. Options include focusing on the top selling vehicle models covering as much market as possible, or using international CO_2 emissions data after extremely careful matching of vehicle models.

The method for calculating vehicle sales-weighted fleet average CO_2 emissions is presented in Equation 1. Sales-weighted average values represent more closely the average emissions of the evaluated vehicle fleet, either a national fleet or a manufacturer fleet.

Equation 1

$$FA\_CO_2 = \frac{\sum_{i=1}^{n} CO2_i * Sales_i}{\sum_{i=1}^{n} Sales_i}$$

Where FA_CO_2 is the vehicle sales-weighted fleet average value for a fleet of n model vehicles, each of them with a CO_2i emissions value and sold at $Sales_i$ value during a defined period of time (model year, calendar year or fiscal year). The same formulation is used to calculate the vehicle sales-weighted fleet average reference parameter, either vehicle mass or vehicle size.

As an example, let us assume a market where only two vehicle models are sold, a compact car that emits 110 gCO_2/km and a sports utility vehicle (SUV) that emits 180 gCO_2/km (Table 5). Let us assume that 1000 units of the compact car and 500 units of the SUV are sold during a given year. Sales weighted average CO_2 is calculated by adding up the product of CO_2 emissions times sales numbers for each model, and then dividing by total sales: (1000*110g CO_2/km+500*180g CO_2/km)/(1000+500) = 133 gCO_2/km, which represents the average vehicle for that fleet of 1500 vehicles sold by Manufacturer X that year. Note that the example uses the same method to calculate sales weighted average vehicle mass, which is the reference parameter for some CO_2 standards. Figure 4 is an example of the same analysis for European manufacturers and for the entire fleet, and is referenced to vehicle mass.

The same methodology is applied to the overall fleet to calculate fleet average values, as well as manufacturer average values. The number of model vehicles to be evaluated varies between 700 to 2000, and manufacturers range between 10 and 30 depending on local market conditions. Note that the analysis is done by manufacturer and not by brand (e.g., Volkswagen group, as a manufacturer covers the brands Volkswagen, Audi, Skoda and others). The analysis should consider the legal entities registered to sell vehicles within the country.

Table 5 – Example of calculation to determine manufacturer sales weighted average values

Manufacturer X	Model A	Model B
Sales	1000	500
CO_2 emissions	110 g/km	180 g/km
Mass	1000 kg	2000 kg
Sales Weighted Average CO_2	$\frac{(1000*110)+(500*180)}{1000+500}$ = 133 g/km	
Sales Weighted Average Mass	$\frac{(1000*1000)+(500*2000)}{1000+500}$ = 1333 kg	

3.1.2 Fleetwide GHG emission model development

Construction of the fleetwide GHG emission model is required to estimate BAU scenario GHG emissions and the relevant intervention scenario emissions to be able to estimate the emission reduction potentials of the GHG/FE standard. The list of data requirements is:

– Calculated fleet average CO_2 emissions or fuel economy (CO_2/km or equivalent metric). Single value for average new vehicle on a given year.
– Vehicle stock/registration data
– Vehicle fleet-average activity data and activity-deterioration curves
– Vehicle activity change assumptions due to GHG/FE standards (rebound effect)
– Vehicle survival rate or retirement curves
– Data needed to project fleet growth: GDP, population and other economic activity growth indicators
– Defined time window for the analysis

The annual rate of CO_2 emissions from the passenger vehicle fleet can be estimated for a given year by multiplying the sales-weighted average CO_2 emission value (g/km) times vehicle activity (km/year), times the number of vehicles entering the fleet and survival rates (Equation 2).

Equation 2

$$Annual\ Total\ CO2_k = \sum_{j=Y1}^{j=k} FACO2_j * N_j * VKT_j$$

Where,
Annual Total CO_{2k} is the total CO_2 emissions in year k, in tons
$FACO_{2j}$ is the sales-weighted fleet average CO_2 emission value (g/km) for the fleet of vehicles in year j
N_j is the number of vehicles in year j (Y1 being the first year)
VKT_j is the vehicle kilometers travelled per vehicle (km/year) in year j

The number of vehicles that remain registered and their activity change according to vehicle age. This implies that N_j and VKT_j values change over time with respect to values "as new", on year k.

Vehicle retirement rates are mathematical functions that describe the probability of finding a vehicle operating after certain age. The probability functions are known as vehicle retirement curves or vehicle scrappage curves and are developed for specific vehicle types, as heavy-duty vehicles have much longer operational spans than light-duty vehicles or motorcycles. The Weibull cumulative distribution function shown below is used to characterize the probability, and can be tailored to local markets and vehicle types by changing its constants (Equation 3).

Equation 3

$$P_r(y) = e^{-\left(\frac{y}{\beta}\right)^{\alpha}}$$

Where Pr(y) is the probability of the vehicle remaining operational; y is the age of the vehicle; and α and β are parameters that can be adjusted to local markets and vehicle types.

The number of vehicles, i.e. stock, in a given year can be estimated by adding up the product of historic sales in previous years times their probability of remaining operational according to age (Equation 4).

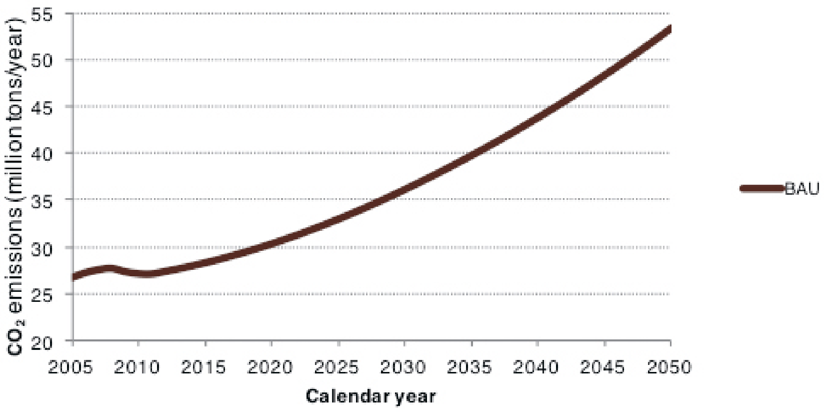
Equation 4

$$N_j = P_r(y) \cdot S_j$$

Where S_j is the number of vehicles sold in year j. Note that the number of vehicles that remain operational in year j, N_j, is lower than the sales of year j.

Figure 5 shows an estimate of annual CO_2 emissions from the passenger vehicle fleet in Mexico[9] It uses new passenger vehicle fleet average emission values for MY2012 (the latest available), estimated at 151 gCO_2/km. New passenger vehicle sales in 2012 were around 650 thousand units; future vehicle sales projections were based on official sources on economic growth. The data presented here were obtained from government sources for a recently published cost-benefit analysis of implementing the next phase of FE/CO_2 standards in Mexico (Posada et al., 2017). Note that new vehicle sales were impacted during the 2008–2011 global economic crisis, captured in total CO_2 emissions estimates. Retirement rate parameters were set at α =1.9 and β = 25, matching Mexican national registration numbers. Future fleet growth was set at 1.8% per year. Average VKT values were assumed constant along the evaluation period.

Figure 5 Example of ex-ante emissions calculations for the Mexican passenger vehicle fleet under BAU conditions.



[9] This example is available in the excel tool FESET.xlsx published with this report.

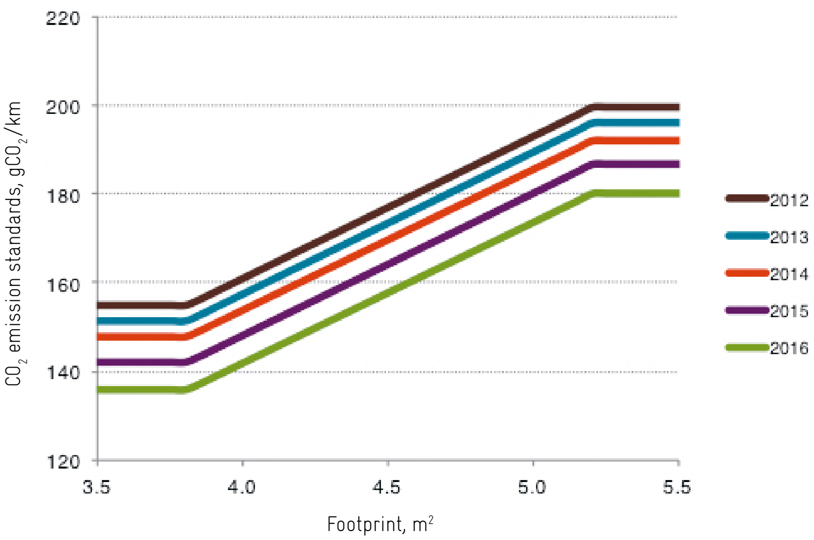
Assessment of the impact of GHG/FE standard

Under ex-ante evaluations, there are only two main methodological differences on fleetwide CO_2 emissions between the BAU and Regulated scenarios: a) the fleet average CO_2 value would change under the regulated scenario based on FE/GHG standard design-stringency and timelines; and b) VKT average values would be affected under the regulated scenario due to the rebound effect. The remaining model inputs should remain the same for both scenarios. Consequently, the impact of a new vehicle fuel economy standard requires defining policy scenarios and assessing their effects compared to the BAU scenario. Under ex-post evaluations the models are basically the same, but actual values can be used for fleet-average CO_2 emissions and new vehicle sales, while corrections may be made to VKT and vehicle stock.

Defining the new-vehicle GHG or FE standard is not part of the baseline determination or monitoring process, but is the most important input that comes from the GHG/FE policy design process, affecting the overall impact of this type of mitigation action. There are important synergies between GHG/FE policy development and monitoring and reporting activities for NAMAs, as all the analysis required is also included within a wider analysis required for standard policy development, (e.g., policy scenarios and cost and benefit analysis). Analysis tools, data, and modeling inputs and outputs can be shared and made consistent for both national policy development and NAMA purposes.

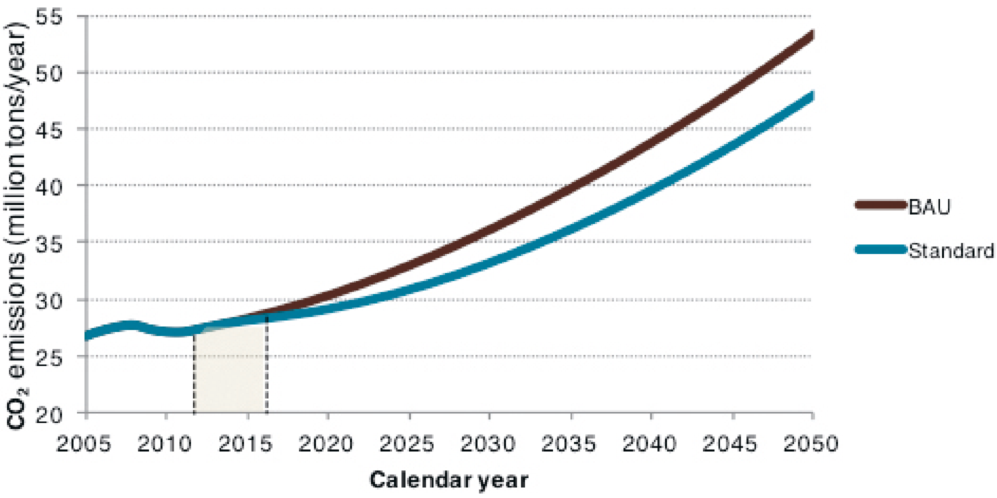
The regulated scenario requires new-vehicle GHG/FE targets for the projected fleet. Those regulatory targets are used as inputs for those years covered under the regulatory timeline. Figure 6 shows the regulatory targets for Mexico between 2012 and 2016 (DOF, 2013). Mexico's standards follow closely the structure of the U.S. targets for passenger cars, which are also harmonized with Canada's targets. Mexican passenger vehicle emissions standards use vehicle footprint as the reference parameter. As the sales-weighted fleet average footprint is 3.7 m^2, the annual target changes from 155 gCO_2/km in 2012 (a voluntary target) to 137 gCO_2/km in 2016; note that the actual performance of the new passenger vehicle fleet in 2012 was 151 gCO_2/km, overcomplying with its voluntary target.

Figure 6 Mexico Passenger Car CO_2 standards for 2012–2016. Source DOF (2013)



The impact of implementing the new vehicle CO_2 standards is shown in Figure 7. The shaded area represents the period of regulatory implementation, 2012 to 2016. The benefits increase over time, in small amounts during the early years of regulatory adoption, and at higher rates later as older and less efficient vehicles are removed from the fleet and newer efficient technologies start to take over a larger share of the growing fleet. At the end of the regulatory implementation, the benefits amount to less than 1% emission reduction with respect to BAU emissions, but by 2035 benefits reach a long term steady value of 9%.

Figure 7 Assessment of the impact of GHG/FE standard for Mexico. The standards cover new vehicles model year 2012 to 2016 (shaded area)



Real world GHG/ FE performance of new vehicles

The new vehicle CO_2 emissions data used in the ex-ante model to estimate fleet average CO_2 emissions values come from laboratory test carried out under specific driving conditions. Those driving conditions may not entirely represent the driving behaviour of the local market, often resulting in a gap between laboratory and real-world CO_2 emissions.[10] For ex-ante analysis, real-word GHG/FE adjustment factors can be included in the model to account for that effect on total benefits. This adjustment helps to better reflect the performance of the new vehicles in the local market, better predict their impact on the GHG inventory model, and, most importantly, better estimate the fuel consumption reduction which is a key input for regulatory cost payback analysis.

It is possible to account for the CO_2 emissions gap by applying a factor to the sales weighted average CO_2 emissions input into the model. In the example case for Mexico, where the gap has not been evaluated yet, a gap value similar to that found the US is used. The US vehicle fuel efficiency gap between certification data (laboratory) and real-world values have been calculated by U.S. EPA to be around 17–23%.

Ex-post analysis

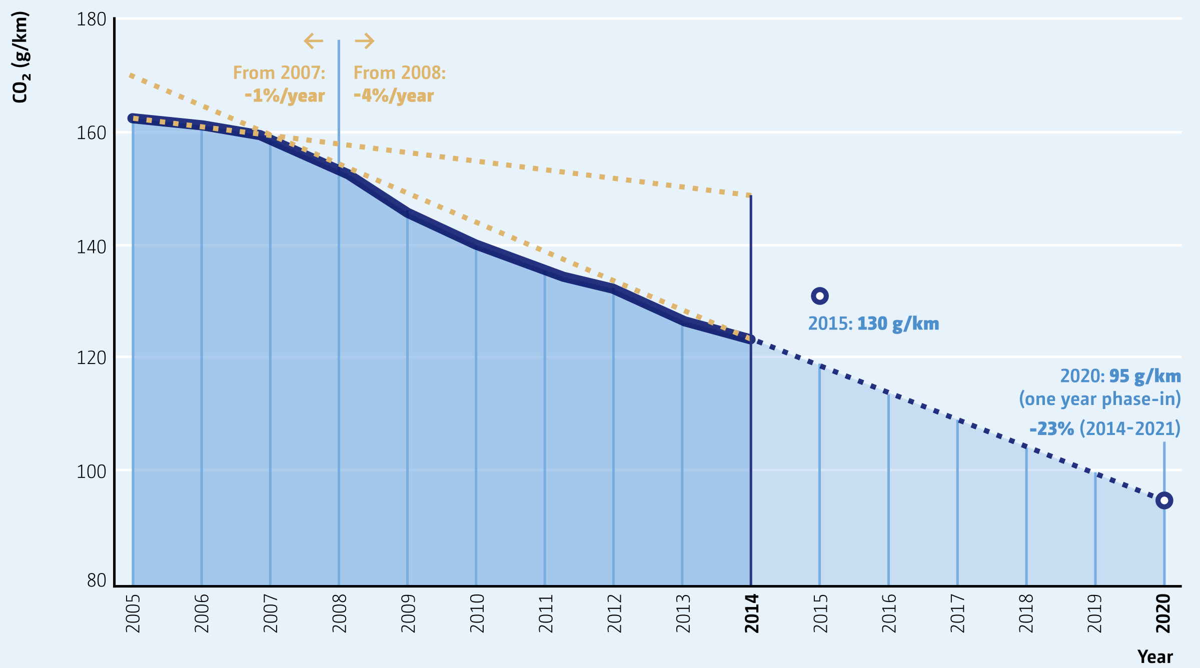
Several levels of corrections can be carried out to estimate the effects of this intervention compared to the effect calculated with ex-ante data. Achieved or measured data inputs available for ex-post analysis are:

- achieved new-vehicle fleet average GHG/FE values, which tend to be better than the targets, as manufacturers tend to over-comply with the regulation;
- actual new-vehicle sales can be used and fleet growth can be better modelled;
- actual fuel consumption at the pump can be used via top-down models to estimate the impact of the regulation in terms of total fuel use and GHG emitted, or to correct fleet activity data.
- Ex-post inputs can also include updated VKT and rebound effect assumptions, from dedicated studies on vehicle activity planned in parallel with regulatory and MRV development.
- Ex-post analysis could benefit from a national study to measure the performance of a sample of new vehicles and determine the magnitude of the actual laboratory to road fuel economy gap to better reflect CO_2 improvements of this type of intervention. Note that measured gap has only been reported in the US and Europe.

Figure 8 shows an example for CO_2 standards target evolution for EU passenger cars in place since 2008. EU targets change over time and exhibit a rate of annual improvement around 4% per year, from 130 g/km for 2015 to a target of 95 g/km by 2020/21. The difference between fleet target values and achieved fleet performance values illustrates the different inputs for ex-ante (target) and ex-post (achieved) evaluations.

Tietge W., Zacharof N., Mock P., Franco V., German J., Bandivadekar A., (2015). From laboratory to road: A 2015 update. The International Council on Clean Transportation (ICCT). Washington.

Figure 8 – Historic progression of passenger car fleet average CO_2 emission standards and fleet performance. X-marks indicate regulated targets. The thick blue line shows the actual performance of the regulated fleet, while the dotted line shows the trend towards future targets. Source: ICCT.



Blue-white dots indicate regulated targets. The thick blue line shows the actual performance of the regulated fleet, while the dotted line shows the trend towards future targets. (ICCT)

3.2 Uncertainties and sensitivity analysis

Uncertainties in calculating the ex-ante impact of this type of mitigation action arise from input availability and quality. Uncertainties can be found in key variables as well as external variables that are not directly affected by the mitigation action but that impact its outcome, such as fuel price variations. Lack of available data regarding local VKT values, and retirement and VKT degradation curves, as well as stock numbers and used imports generate uncertainties that ought to be declared for ex-ante reporting. Table 6 lists the main uncertainties for ex-ante BAU and intervention scenario accounting.

Table 6 – Main GHG/FE modeling uncertainties

Variables	BAU	Intervention
New vehicle fleet average CO_2	Uncertainty on projected new fleet average CO_2 values. Future values could be affected by vehicle market response to fuel pricing variations.	Uncertainties from sales weighted average determination (quality and quantity of available data). Uncertainties due to deviation of new vehicle GHG/FE data vs. real world performance data. Future values could be affected by vehicle market response to fuel pricing variations.
New vehicle numbers	Fleet growth is dependent on growth modeling assumptions, GDP and/or population.	
In-use vehicle stock numbers	Uncertainties arise from data quality and availability of retirement curves. Vehicle outflows (retirement) data is typically unavailable, relying on international default curves.	
Used imports numbers	Uncertainties arise from data quality and availability.	
Vehicle activity	Uncertainties due to data quality and rebound effect assumptions.	

An ex-ante sensitivity analysis could consider:

- Projected values for new vehicle fleet average CO_2 emissions values under the BAU scenario including three cases: no improvement with respect to baseline year value, a moderate decline case, and a moderate improvement case.
- Rebound effect on vehicle activity could be modeled under mid, high and low cases based on data found in literature.

4. Guidance on the selection of analysis tools for new vehicle GHG and fuel economy standards for light-duty vehicles

Modeling the impact of new vehicle GHG/FE standards on total GHG emissions entails a straightforward bottom-up approach that requires paying special attention to the input variables involved. The main variables for ex-ante analysis are new-vehicle fleet-average CO_2 emissions value (emission factor), new vehicle sales and in-use vehicle fleet (vehicle numbers) and average kilometer traveled (average vehicle activity data). Table 7 presents a list of variables and where to use aggregated and disaggregated data.

Table 7 – Level of disaggregation of key variables

	Degree of local data disaggregation		
Variable	**Lower accuracy**	**Medium accuracy**	**Higher accuracy**
New-vehicle fleet-average CO_2 emissions	Fleet-average values obtained from total fuel sales data via top-to-bottom analysis. This can be used to estimate the value corresponding to the current in-use stock of vehicles.	Fleet average CO_2 values from partial new vehicle fleet databases: data on the top x% vehicle models sold in target market. Fleet-average CO_2 values based on aggregated new vehicle databases, i.e., by vehicle segment (small car, medium car, large car, sports, van), or by vehicle manufacturer.	Fleet-average CO_2 values would be ideally calculated from disaggregated, model-by-model, vehicle databases sourced from manufacturers or government officials, or from commercial vehicle market analysis companies.
Vehicle numbers: new vehicle sales, stock, and used imports	Total vehicle numbers are helpful for overall fleet consumption and very basic estimates. Stock numbers and used imports may be available as aggregated values only.	Sales numbers may be available by manufacturer or by segment. This can be used for cross validation of other data sources. Used vehicle import numbers by vehicle segment (cars and light trucks) may be available from government agencies.	Disaggregated model-by-model sales data is ideal for new vehicles.
Vehicle numbers: new vehicle sales, stock, and used imports	Average vehicle activity for light-duty vehicles is a single value input for this type of MRV analysis. Some level of disaggregation can be found for two LDV types: light passenger cars and light-trucks. However, how VKT data is determined affects the accuracy of the model output:		
	Lower modeling accuracy if VKT is adapted from other markets when not available in local market.	Medium modeling accuracy if the VKT value use has been corrected to local markets based on total fuel use or any other statistical method.	Higher modeling accuracy is obtained if the VKT comes from a recent study on local market vehicle activity. This is ideal for ex-post analyzes.

4.1 Description of tool types

Modeling tools are typically developed as Excel spreadsheets, making them easy for users to adapt to specific markets. Where most modeling tools may differ is in the calculation of new-vehicle fleet-average CO_2 emission values, which depends on data granularity. The other differentiation aspect is the ability to estimate the impact of the GHG/FE standard with respect to total fleet stock, current and new vehicles, including retirement rates and VKT degradation factors and real-world GHG/FE adjustments.

As an example, IEA's FEPIT requires new-vehicle sales and CO_2 emissions data input by segment, and the model calculates the new vehicle fleet average CO_2 value and fleet wide GHG emissions. Vehicle data by segment can be also used with the tool by the regulator to develop other complementary policies such as CO_2-based taxation programs. GHG/FE regulatory targets can be input as percent annual reduction targets. FEPIT however does not account for the in-use fleet stock numbers and fuel economy values, and has no options for accounting for used-vehicle imports or real-world gap. This is a significant limitation of FEPIT, as the impact of the new vehicle GHG/FE standards (i.e., regulated vs. BAU scenarios) is reduced to new vehicles only, which greatly underestimates the positive impact of an efficient new-vehicle fleet as older, inefficient vehicles are retired from the stock fleet.

Another example of an available bottom-up tool for studying the effect of adopting new vehicle GHG/FE standards is the Roadmap Tool developed by the ICCT. The Roadmap was developed as an accounting tool for the global impact of GHG and FE policies. It can be adapted as a preliminary impact assessment tool during early monitoring and reporting development stages. The main difference with FEPIT is that the new vehicle GHG/FE value is input by vehicle type, (LDV being the relevant one for this audience). The Roadmap tool also has a pre-loaded set of country data on VKT and fleet numbers from 11 countries and regions that the user can adapt to their local needs. This tool does include the in-use fleet in the GHG inventory calculation, accounting for the retirement of older inefficient vehicles. Other relevant policies that can be studied with the Roadmap tool are electric vehicle adoption, mode shift, and fuel and electric grid decarbonization.

A simpler, bottom-up publically available model is the Center for Clean Air Policy (CCAP) Transportation Emissions Guidebook. The purpose of the guidebook is to provide basic rules of thumb providing rough emission reduction estimates from a wide range of transportation, fuel and land use measures. The CCAP Guidebook has a significant amount of default data based on US transport characteristics, requiring careful considerations when adopting it to other countries.

The ICCT developed a new bottom-up tool, focusing on the evaluation, ex-ante and ex-post, of adopting new vehicle fuel economy or CO_2 emission standards on light-duty vehicles. The ICCT tool on vehicle GHG/FE standards evaluation (FE Standards Evaluation Tool - FESET) provides a simple bottom up evaluation method split in several sections. The first section is focused on fleet average CO_2 emissions value determination, requiring a detailed fleet database. However, a simplified database, and even a single fleet average value, could be used as the input for the following relevant sections. The second section is where the annual fleet CO_2 targets are input. The third section provides the total annual fleet CO_2 emissions calculation inventory, including fleet numbers (historic and projected), vehicle activity, and vehicle retirement curves. Predefined curves for activity degradation, vehicle retirement curves, real world fuel economy gap, and VKT rebound effects are provided. The fourth section covers ex-post analysis, and allows the user to input achieved fleet average CO_2 emissions values, actual registration numbers and any other modeling updates produced after ex-ante analysis. The final section, containing outputs, provides a summary of fleet CO_2 emissions results for ex-ante and ex-post analysis. A detailed description of this model is provided in the last section of this document.

Models and most numerical tools developed by regulatory agencies use granular CO_2 emissions and sales data as the input to estimate the new vehicle CO_2/FE fleet-average value. Thus, the first step to adapt/develop ex-ante inventory tools for GHG/FE standards is to perform an accurate assessment of the performance of the baseline new vehicle fleet. From that step onwards, the MRV analysis could make use of the FEPIT, Roadmap, FESET, or any other developed GHG accounting models to evaluate this type of mitigation.

Table 8 presents a qualitative estimation of the level of effort and technical capacity required to use the methodology.

Table 8 – GHG/FE Inventory models

Name	Summary	Scope	Computer based	Methodology documentation	Data collection guidance	Defaults Provided	Cost	Developer
FEPIT	Estimates the impact of policy measures on the average fuel economy of newly registered cars	LDV fuel economy standards CO_2-based vehicle registration tax/feebate scheme CO_2-based vehicle circulation tax/feebate scheme Fuel taxation	Yes, Excel sheet. Inputs can be changed	Very good	No	Yes Global FE improvement rates Predefined target values Predefined vehicle segments FE values	Free	IEA
ICCT Roadmap	Shows trends and assessed emissions and energy-efficiency implications of different policy options on GHG and pollutant gases	GHG/FE standards Modal shift, Lower carbon fuels EV adoption	Yes, Excel sheet. Inputs and parameters can be changed	Very good	No	Yes GHG emission factors for all sectors Predefined country values for fleet stock and growth	Free	ICCT
CCAP Emissions Guidebook	Fuel efficiency incentives Anti-idling campaigns Vehicle scrappage feebates	Ex-ante tool; sketch planning estimates based on combining local data and defaults;	Yes	Good	Fair	Emission factors for US fleet, other factors can be entered Uptake rates	Free	CCAP
FESET	Assessment of adopting FE/CO_2 emission standards in new vehicles,	National standards BAU vs Mitigation action evaluation Ex-ante and ex-posts evaluations	Yes, Excel sheet. Inputs can be changed	Good	Fair	Vehiclel activity VKT degradation Retirement rate curves Real world FE gap Rebound effect	Free	ICCT

5. Monitoring

Periodic evaluation of key components of the mitigation action is required to track the performance of the mitigation action. The implementation of the new vehicle GHG/FE standards regulation for light-duty vehicles is the starting point for monitoring, reporting and verification of this type of mitigation action. The standards regulation itself contains the timeline of adoption, evaluation cycles, and the expected targets, limiting modeling assumptions and reducing the uncertainty for ex-ante analysis.

Performance indicators are based on ex-ante regulatory targets, while the ex-post work can be performed following regulatory compliance evaluation. New vehicle sales can also be provided by regulators, or obtained directly from manufacturers or commercial data vendors. Changes to VKT values can be revisited during the preliminary regulatory and mitigation design phases, and can also be planned for update as part of the mitigation action development and implementation.

Impact indicators on GHG emissions and fuel consumption are the result of the CO_2 emissions and fuel economy data provided by regulators, and updated vehicle fleet numbers and VKT values. In that regard, impact indicators can be presented annually, after the end of the regulatory cycle. Impact indicators would be affected by the accuracy of VKT values, which suggests that even though the ex-ante analysis can be carried out with default VKT values from other markets, a study of national VKT values would increase the accuracy of ex-post evaluations.

Table 9 – Minimum indicator set for new vehicle GHG/FE standards mitigation action

Category	Indicator	Normal monitoring frequency
Implementation indicator	Adoption of GHG/FE Standard	Upon regulatory adoption, and for each new regulatory phase
Performance indicators	New vehicle GHG/FE sales-weighted average values New vehicle sales VKT fleet average values	Annually, after each regulatory cycle Annually, after each regulatory cycle In preparation for new regulatory cycles
Impact indicators	Fuel consumption	Annual, information from total gasoline and diesel used for passenger vehicles
	Final GHG results	Annually or after each compliance cycle along the extension of the regulatory timeline

Compliance and enforcement activities

The adoption of the FE/CO_2 standards regulation entails the implementation of compliance and enforcement systems. The compliance system covers data management and regulatory compliance determination; most of this process involves desk work. The enforcement system covers the measures to verify some of the data and results pertaining to compliance determination; most of this process is carried out as vehicle testing. Ideally, enforcement would include considerations to make sure real-world CO_2-emission reductions and fuel savings are achieved. This may entail developing local technical capacity, laboratories, testing methods and staff training, planned in parallel with mitigation action implementation. Financing would be required for developing local capacities.

Regulatory compliance

New vehicle corporate fleet average emission levels can be determined when a complete fleet profile becomes available by the end of the regulated cycle, i.e., model year, or calendar year. This requires that FE test data and sales data are submitted to the authority, as well as a set of additional data used to monitor the fleet. Additional data includes a description of each model vehicle including physical attributes, test conditions, and information relevant to define compliance flexibilities.

Data transfer can be carried out via an electronic system. An excel-based format, or equivalent, common to all manufacturers to input and transfer data into a GHG/FE Standard system is required. The database could also be shared among relevant national stakeholders, such as Departments of Transport, Energy, Industry and Commerce for their own data needs.

The compliance process starts with data submitted by manufacturers (Measurement) and compared against the new vehicle GHG/FE targets set by the regulation. A manufacturer is considered compliant with the respective corporate average GHG/fuel economy standard at the end of the enforcement cycle, calendar year or model year, once the actual corporate sales weighted average values are at or below the target values for that fleet.

Manufacturers are generally given some flexibility for compliance. The idea behind flexibilities is to keep the cost of compliance low while making sure the overall GHG reduction target and GHG benefits are achieved. For annual standards, one of the most important flexibilities is carry forward GHG credits. These allow manufacturers to accumulate excess credits derived from target over-compliance, and use them to achieve compliance for upcoming enforcement cycles. Other common GHG credit flexibilities available to manufacturers are: carry backwards credits allowing GHG deficits to be carried for a defined regulatory compliance period, off-cycle credits for technologies that offer significant benefits in real world driving conditions, and credit transfers among manufacturers.

The authority reaches a compliance decision for each manufacturer after processing the submitted data and using the available flexibilities. Once all manufacturers have been evaluated, a report is issued and shared publically. The GHG/FE report is published annually and shows the corporate average GHG/FE, year by year, and other relevant metrics, including total GHG emissions and fuel consumed. Examples of compliance reports are available from the US EPA and published as the manufacturer's performance report (US EPA, 2016b). An example of CO_2 performance report from the European Union is the European Environment Agency (EEA) public dataset on CO_2 emissions performance of new passenger cars in the EU; this dataset is at the core of the monitoring scheme of CO_2 emissions from passenger cars, and is used by the European Commission to evaluate whether car manufacturers comply with their mandatory CO_2 targets as defined in the Regulation EC 443/2009 (EEA, 2017). These regulatory compliance report examples can be developed by the implementing country and a tailored report based on this type of documents can be produced as part of MRV activities.

Developing a national publically accessible database is a key component of this step. It allows the public to have easy access to information for comparing vehicles during the decision process of buying a new car. It is recommended to build into the website the option for the public to input their own fuel consumption as experienced during daily driving. This helps identify the differences, on a model-by-model basis, between the data provided by the manufacturer and the real driving fuel consumption data provided by the public.

Regulatory enforcement

To deliver on the promise of environmental and economic benefits from new vehicle GHG/FE standards, an effective vehicle enforcement program must be in place to ensure that regulations are effectively implemented. The focal point of enforcement programs is to verify that the information provided by manufacturers is accurate, thus achieving the policy targets set by the regulation regarding GHG emissions and fuel consumption reductions. The main components of enforcement programs can be described as auditing, testing and penalties.

Auditing covers desk-based activities to verify the information provided by the manufacturer and spot potential GHG/FE accounting errors. Auditing actions can include acquiring independent data from independent sources and verifying the original data provided by manufacturers. Also, recalculating target evaluation and GHG credit management for each manufacturer and among manufacturers.

Testing, in the traditional sense, focuses on reproducing the test carried out by manufacturers on vehicles in the market and in circulation and comparing the results against the data submitted to the authority. In this case the tests are carried out by independent technical bodies or in certified laboratories operated by the authority. Countries without access to testing laboratories and equipment can rely on desk auditing activities during the early years of GHG/FE standards enforcement.

Although repeatable and required for basic vehicle certification/type-approval processes, traditional testing under laboratory conditions has shown discrepancies with respect to real-world driving emissions and fuel consumption. As an example, real-world CO_2 emissions of passenger vehicles in Europe are about 9–42% higher than the official values presented by manufacturers and provided to consumers (Tietge et al., 2017). Real-world NO_x emissions of diesel passenger vehicles are about 6 times the emissions measured under traditional laboratory testing (Franco et al., 2014).

One of the reasons for the discrepancy between official and real-world fuel consumption and emission values of new passenger cars is shortcomings in the certification testing programs and in the compliance protocols. Vehicle manufacturers are increasingly able to exploit tolerances and flexibilities built into the testing protocols, leading to downward-trending type-approval emission levels that are not matched by a similar decrease in real-world emission levels–indeed, the real-world values contradict the type-approval results. The uncovered use of illegal defeat devices, also known as Dieselgate, crosses a line between illegality and the simple exploitation of legal loopholes that allow manufacturers to observe the letter of a regulation while disregarding its spirit and intent (US EPA, 2017). But it nevertheless serves to dramatically highlight a broader underlying problem with today's vehicle emissions testing and compliance systems. Real world emissions measurement, not just for air-pollutant emissions, but also for fuel consumption and CO_2, could be introduced to improve the enforcement program.

This implies that the testing element of the regulatory enforcement ought to be planned in three phases. The first phase covers simple desk verifications, the second phase requires traditional vehicle testing, and the third phase expands vehicle testing into real-world testing. The second and third phases imply developing the technical capacity, laboratories, testing methods and staff training. They can be planned in parallel with the implementation of the GHG/FE standard and executed under a reasonable timeline. International laboratories can also be hired for vehicle testing during the first phase of regulatory adoption. Other less expensive testing options include capturing data directly from the vehicle, or using simpler, portable measurement equipment that can be transported in and out of the country.

Economic penalties are an important tool for regulators to ensure regulatory compliance. Penalties apply when a manufacturer fails to meet the GHG/FE standard and has not generated, or purchased via trading, enough credits to cover the fleet average requirement within the specified number of years. Penalties for non-compliance are an important part of ensuring that the fuel consumption reduction goals of the regulation are eventually met. It is important to set financial penalties at a level high enough to provide a strong incentive to comply with the standard rather than simply to pay the penalty. In other words, in order to make compliance the most cost-effective option, the penalties should be higher than the cost of the technology required to reduce fuel consumption. Penalties should be triggered automatically for non-compliance, after exhausting all available GHG credit flexibilities, and should be built into the regulation that sets the standards.

Parallels between MRV and regulatory compliance and enforcement programs

Monitoring, reporting and verification activities that are carried out within the NAMA framework can be supported by regulators at the national level that oversee GHG/FE standards compliance. A memorandum of understanding between the branches of the government in charge of the standards, as well as with international verification bodies, can benefit MRV adoption by allowing access to disaggregated actual data produced during the regulatory cycles. The implementation process could benefit from synergies with local governments by providing access to data or developing better mechanisms to monitor the fleet, via studies on vehicle activity and real-world consumption of fuels. These measures have the potential for local capacity development (i.e., local research organizations can be tasked with updating or developing national VKT and real-world fuel consumption data), thereby adding to the MRV societal benefits.

6. Example – Impact of New Vehicle CO_2 Standards in Mexico

Mexico is the second largest market for new passenger vehicles in Latin America and has been setting records for growth of vehicle sales, with 1.6 million new cars and light trucks sold in 2016. In 2013, the Secretary of Environment and Natural Resources (SEMARNAT) adopted NOM-163-SEMARNAT-ENER-SCFI-2013, which set mandatory manufacturer-fleet average emission limits for CO_2 from new light-duty vehicles for years 2014 through 2016, with voluntary targets for 2012 and 2013. The new vehicle fleet average CO_2 emissions changed from 151 gCO_2/km in 2012 to an estimated 136 gCO_2/km in 2016, a 10% improvement.[11] Mexico is currently working to develop Phase 2 of its LDV GHG/FE standards. In the most ambitious scenario studied, the fleet average fuel economy for model year 2025 vehicles would achieve 108 gCO_2/km, a 28% reduction on fleet average fuel consumption from 2016 levels.

Evaluating the ex-ante impact of Phase 1 GHG Standards for Mexico

The scope and boundary conditions that define the analysis using the Fuel Economy Standard Evaluation Tool (FESET) developed for this project, and applied to Mexico's fleet, are presented in Table 10.

Table 10 Scope and Boundaries of FE/GHG Standard

Boundary element	Example
Sectorial boundary	For this example, we used Mexico's passenger vehicle (PV) fleet. Note that the Mexican new vehicle FE standard regulation has independent targets for passenger vehicles and light trucks, and both are considered Light-Duty Vehicles under Mexican vehicle classifications.
Geographic boundary	Mexico's new vehicle FE standard is a federal standard.
Temporal boundary	For this example, we used Mexico's current FE standard program; it covers 2 years of voluntary compliance (2012–2013) and 3 years of mandatory compliance (2014–2016). The impact analysis covers a larger period, extended to 2050.
Regulatory target	The current example covers CO_2 emissions only.
Sustainability effects	Fuel consumption conversion is calculated as gasoline equivalent

[11] The fleet average CO_2 emission value for 2012 was calculated by ICCT from ex-post data. The 2016 value was estimated based on regulatory targets and projected fleet characteristics. Official fleet average CO_2 emissions data are not available as of writing of this document, but they are expected by the end of 2017.

Baseline input data

This section is where the user inputs the detailed vehicle by vehicle data required to calculate the new vehicle sales-weighted fleet average FE/CO_2 values and reference parameter (mass or size). Note that the key required data are: Year, Manufacturer (Company), Model, Sales (Quantity), CO_2 emissions/Fuel Consumption, and Weight or Footprint (depending on how the target is referenced). Additional inputs that may be used for baseline analysis or standard-making are power (hp) and fuel type.

The use of this spreadsheet is optional. It has been included here as a way to provide a consistent analysis framework for interested parties. The main objective is to identify the primary inputs that FESET users would need to collect and how they are used.

For the example provided in the tool, the data was obtained from Mexican authorities and it was required to be kept anonymized as it is currently part of compliance evaluation (Figure 9). The inputs for example models are aggregated data in order to represent the actual specification of the Mexican fleet while limiting the length of the example list. The actual list of inputs is usually much longer than the example list because of the large number of models available in each market. The user can copy from any database and paste into the tool and add rows if needed, for tailoring the analysis to other markets.

Figure 9 ICCT FESET, Baseline input data. Example for Mexico's passenger car fleet

Collect and organize available fleet information

Key vairables to be monitored
Additional useful information used in the example
Additional useful information that can be used for analysis, not used in the example
Calculation process

Year	Manufacturer	Model	Segment	Sales	CO2 Emissions (g/km)	Fuel consumption (gasoline equivalent l/100km)	Weight (kg)	Footprint (m^2)	Power (hp)	Fuel
2012	A	A1	Subcompact	843	215	10.9	1462	3.8	265.3	
2012	A	A2	Subcompact	3821	153	15.2	1215	3.6	177.6	
2012	A	A3	Large SUV	421	213	11.0	1572	4.6	229.0	
2012	A	A4	Midsize	2809	222	10.5	1639	4.6	295.9	
2012	A	A5	Compact	1826	233	10.0	1655	4.2	328.9	
2012	A	A6	Large	843	286	8.2	2068	5.0	399.5	
2012	B	B1	Subcompact	22711	116	20.2	945	3.4	84.5	
2012	B	B2	Subcompact	4014	144	16.2	1024	3.2	112.6	

Baseline analysis

The baseline analysis sheet provides basic analysis useful to understand the specifications and performance of the fleet, and for comparisons with other years or other markets (Figure 10). The main output is only a pair of numbers that are presented on rows titled Fleet average (Row 5). Additional analysis, by company and by segment are shown here as a way to describe the fleet, but the values are not used beyond this point.

In the example for Mexico for Year 2012, with around 631,000 passenger cars sold, the sales weighted average CO_2 was 151 g/km and the fleet average footprint was 3.7 m^2. These are the two key values required to study the impact of the FE/CO_2 standards in Mexico. For countries that plan to establish fuel economy standards based on vehicle weight, the fleet average weight would replace footprint as the key value.

Figure 10 ICCT FESET, Baseline analysis. Example for Mexico's passenger car fleet

Mexico 2012 passenger car baseline analysis

Fleet average

Year	Company	Segment	Quantity	Emissions (g/km)	l/100km	Weight (kg)	Footprint (m2)	Power (kW)
2012			630913	150.80	15.8	1193	3.7	134.3

By company

Year	Company	Segment	Quantity	Emissions (g/km)	l/100km	Weight (kg)	Footprint (m2)	Power (kW)
2012	A		10563	203	12.0	1506	4.1	262.0
2012	B		35967	143	17.5	1112	3.6	120.3
2012	C		7477	205	12.8	1644	4.0	319.7
2012	D		54165	155	15.3	1270	4.0	148.3
2012	E		117	272	8.6	1846	5.1	452.4
2012	F		143983	141	16.7	1101	3.5	104.1
2012	G		24867	159	14.8	1271	4.0	148.5
2012	H		167518	140	16.8	1110	3.7	119.4
2012	I		2845	165	14.2	1275	3.9	121.7
2012	J		151	208	11.3	1478	4.4	202.6
2012	K		8193	146	16.0	1105	3.6	119.8
2012	L		24701	176	13.3	1274	3.9	149.4
2012	M		150366	161	14.6	1297	3.8	155.6

By segment

Year	Company	Segment	Quantity	Emissions (g/km)	l/100km	Weight (kg)	Footprint (m2)	Power (kW)
2012		Compact	84637	163.7	14.4	1388.8	4.1	172.1
2012		Subcompact	486486	144.0	16.4	1111.7	3.6	114.1
2012		Midsize	55740	183.7	13.1	1545.3	4.5	235.9
2012		Large	3284	258.4	9.1	2037.5	5.0	390.8
2012		Large SUV	765	203.1	11.6	1755.9	4.7	263.1

Standards

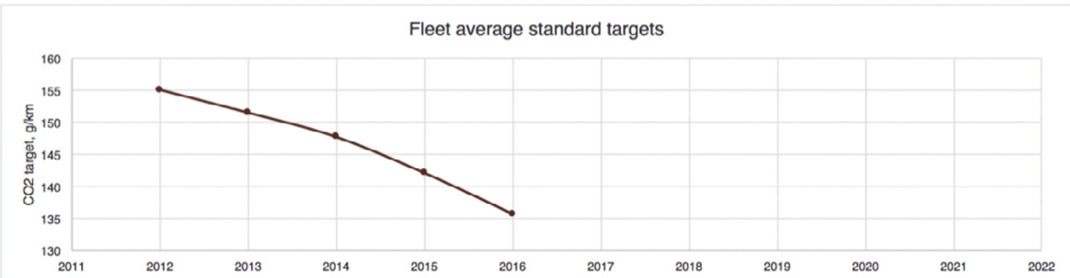
This sheet allows the user to input annual targets according to the FE/CO_2 targets set by the regulation for the vehicles covered under the regulatory scope. CO_2 targets can be input manually in cells B6 to K6 (Figure 11). The year and the corresponding target value, in g/km, are required. The values listed here are directly used by the inventory calculation sheets, ex-ante and ex-post.

Figure 11 ICCT FESET, Standards inputs. Example for Mexico's passenger car fleet

Standards input Data

	Regulated Years									
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Defined by regulation	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO2 target, g/km	155.1	151.5	147.7	142.1	135.7					

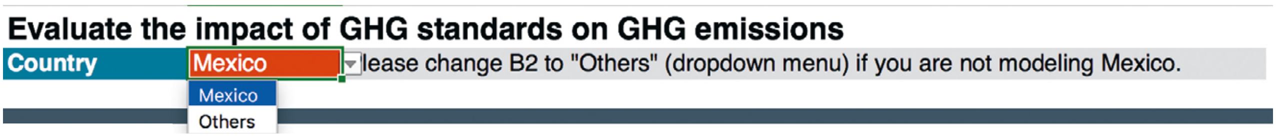
Note: CO2 targets can be input manually in cells B6 to K6. The values listed here are an example from Mexico's PV GHG Targets (below, rows 21+)



BAU vs regulation GHG

This is the core sheet where annual CO_2 emissions are calculated based on a series of inputs and model assumptions. For the most accurate result, the example model provides some customized data for Mexico (explained later in this section). For best results, users modeling countries other than Mexico should change Cell B2 to "Others" before proceeding with the following steps (Figure 12).

Figure 12 Customize data switch for annual CO_2 emission calculation



There are three parts to the data that users are required to fill in. Basic assumptions (Figure 13) includes model start/end years and standard start/end years. Model start/end years are predefined from 1960 (when a vehicle starts to enter the market) to 2050. The user can extend the Model end year input beyond 2050, but will need to extend the calculation in the rest of model wherever calculation ends in 2050 (e.g. Row 121, 127, 134). The time span for FE/CO_2 standards application is input in the Standard start year and end year, respectively.

Figure 13 Baseline assumption for annual CO_2 emission calculation

Basic assumptions				Note
Model start year	1960	Model end year	2050	Model end year can extend to 2050 or further.
Standard start year	2012	Standard end year	2016	Based on the design of standards (see "Standards" tab).

Key baseline data are presented again in this section as inputs to the model (Figure 14): Baseline year, baseline CO_2 emissions (g/km), Baseline new vehicle sales, and Baseline footprint (informative). These values should match the numbers from the Baseline analysis tab (Fleet average, Row 6). Vehicle stock at baseline year is an optional input, which is only needed if the user does not know the historical sales rate (explained below).

Figure 14 Baseline data for annual CO_2 emission calculation

Baseline data				
Baseline year	2012			User input.
Baseline CO2 emission, g/km	150.8	Baseline Footprint, m2	3.7	Based on available baseline data (see "Baseline analysis" tab).
Baseline new vehicle sales	630,913	Vehicle stock at baseline year	10,566,000	Annual sales number is based on available baseline data (see "Baseline analysis" tab). Manually enter vehicle stock number of the same year to calculate historical sales rate (cell B21).

Modeling assumption data starts in Row 20 (Figure 15). The notes clearly explain the definition and usage of each parameter. Historical sales rate, if unknown to the user, can be calculated using the built-in function in the model based on baseline new vehicle sales and vehicle stock at baseline year. Maximum predicted age, VKT activity level and rebound effect, CO_2 emission reduction without standards, and real-world adjustment factor are predefined values. However, users can revise these inputs customized to their own market.

Note the historical sales rate and CO_2 emission reduction rate are used to predict historical sales and historical CO_2 emissions only if the historical information is not available. For the Mexico example, 2000 to 2012 sales (B71:B83) and 2008 to 2012 fleet average CO_2 emissions (E79:F83) are manually input for more accurate results. These Mexico-specific data will automatically switch off once the user chooses "Others" in the Country list in Cell B2. Users can manually insert available sales and CO_2 emission data in A29:F121.

Figure 15 Modeling assumption for annual CO_2 emission calculation

Modeling assumptions				
Historical sales rate	2.3%	Click to evaluate annual sales growth rate (cell B21)		Historical sales refer to stock fleet size changes before baseline year. Two options are provided: **a)** user can direclty input the value for each of the years, or **b)** user can estimate each value based on baseline year information and historical growth rates: click button on the left to evaluate historical sales growth rate **based on baseline year sale (B19) and stock (D19).** Evaluation result is shown in B21 and reflected in Column B, Start year row to Baseline year row.
Projected sales rate	2.0%			Projected sales rate after baseline year are based on national GDP growth projections, population growth, vehicle fleet growth, or any other relevant economic indicator projection.
Maximum predicted age	50			Model span selected as negligible changes on VKT degradation and retirement rates are expected after 50 years.
VKT activity level (km)	18,200	VKT activity rebound effect	10%	Suggested range for passenger car vehicle kilometer of travel (VKT) is 16,000km to 22,000km annually. Rebound effect: drivers may increase activity by 10% of the fuel consumption reduction rate as operating fuel costs are reduced.
CO_2 emission reduction without standards	0.0%			Without FE standards the fleet average CO_2 emission value can be afected by fuel price variations, fleet structure, and consumer response, and can result in increased values even when technology improvements from regulated markets permeate the local vehicle market. This input can be modified for sensitivity analysis. A 0% value is suggested as central case.
Real-world adjustment factor	20%			Typically in the range of 10% to 40%, depending on model year, certification cycle used, and local driving conditions. User can modify the real world adjustment factor based on local data or use an approximation based on international available data (only US and Europe have measured real word CO_2 deviations with respect to official CO_2 emissions data).

In addition, users have the option to update advanced default assumptions on vehicle survival rate (S30:S32 and Q30:Q81), VKT deterioration rates (U30:U81), and real-world CO_2 emission adjustment factor (I30:I121),

The modeling results are presented in rows 124 to 189, including CO_2 impacts, fuel consumption impacts and real-world effect estimates (Figure 16). The first section, rows 124 to 137, summarizes the calculations of the BAU case and the impact of the standard for each year; a percentage reduction value is also calculated for each year. The real-world impact section (rows 157 to 189) shows the effect of correcting fleet average CO_2 emissions with the real-world fuel consumption gap.

According to the example of the Mexico passenger vehicle fleet in the tool, by 2050 the benefit of the 2012–2016 standard is expected to reduce the total CO_2 emitted from 62 Mt/year to 56 Mt/year, including real world adjustments. The fuel consumption from Mexico's passenger vehicle fleet will decrease as much as 10% each year.

Figure 16 – BAU vs regulation GHG modeling results. Example for Mexico's passenger car fleet

CO2 impact BAU vs. Standard

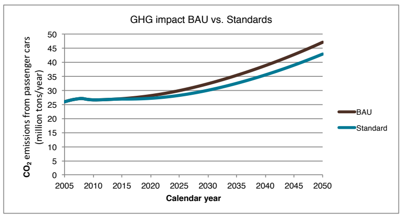
CO2 impact (million tons) = population * VKT *g/km emission per vehicle/10^6

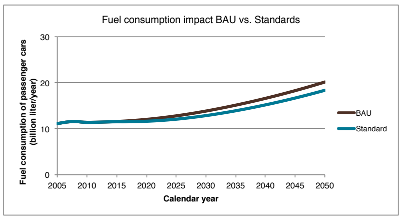
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BAU	26	26	27	27	27	27	27	27	27	27	27	27	27	28	28	28
Standard	26	26	27	27	27	27	27	27	27	27	27	27	27	27	27	27
% Reduction,	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-2%	-2%	-3%	-3%

Fuel consumption BAU vs. Standard

Fuel consumption (billion liters gasoline equivalent) = GHG impact/2336.868

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BAU	11.1	11.3	11.5	11.6	11.5	11.4	11.4	11.4	11.5	11.5	11.6	11.6	11.7	11.8	11.9	12.0
Standard	11.1	11.3	11.5	11.6	11.5	11.4	11.4	11.4	11.5	11.5	11.5	11.5	11.5	11.5	11.6	11.6
% Reduction,	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-2%	-2%	-3%	-3%





Real-world GHG impact BAU vs. Standard

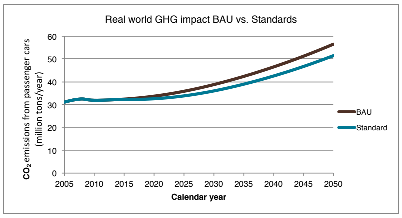
GHG impact (million tons) = population * VKT *g/km emission per vehicle/10^6

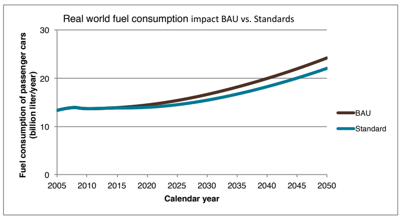
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BAU	31	32	32	33	32	32	32	32	32	32	32	33	33	33	33	34
Standard	31	32	32	33	32	32	32	32	32	32	32	32	32	32	32	33
% Reduction,	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-2%	-2%	-3%	-3%

Real-world fuel consumption BAU vs. Standard

Fuel consumption (billion liters gasoline equivalent) = GHG impact/2336.868

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BAU	13.3	13.6	13.8	13.9	13.8	13.7	13.7	13.7	13.8	13.8	13.9	14.0	14.1	14.2	14.3	14.4
Standard	13.3	13.6	13.8	13.9	13.8	13.7	13.7	13.7	13.8	13.8	13.8	13.8	13.8	13.8	13.9	13.9
% Reduction,	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-2%	-2%	-3%	-3%





Ex-post values

This sheet allows the user to input actual annual fleet average CO_2 emission level after the standards take effect (Figure 17). Fleet sales-weighted average CO_2 emission level in g/km and the matching year can be input manually in cells B8:K9. The values listed in the example are actual CO_2 emission level of Mexico's passenger car fleet from 2012 to 2014.

Figure 17 ICCT FESET, ex-post value inputs. Example for Mexico's passenger car fleet

	Regualted Years									
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Years with available data	2012	2013	2014							
CO2 achieved value, g/km	150.8	145.0	142.0							

Ex-post evaluation

The ex-post evaluation is used to adjust annual CO_2 emissions based on actual CO_2 emission level and fleet growth after the standards take effect. The input surface is nearly the same as "BAU vs regulation GHG". In the Mexico example, passenger vehicle sales from 2013 to 2016 (B84:B87) and fleet average CO_2 emissions from 2013 to 2014 (F84:F85) are updated based on statistics collected from Mexico. Users can also update some assumptions based on actual fleet changes or updated studies, including historical and projected sales rate, VKT activity level, and VKT rebound effect.

The modeling results will present from rows 124 to 189, including the updated evaluation of CO_2 emissions/fuel consumption under BAU and estimated standards scenarios and the ex-post scenario to compare the real impact with the planned impact.

Results summary

This section summarizes the main modeling input, ex-ante and ex-post results (Figure 18). The user can select the years for with the analysis is relevant. In this example, 5-year periods are presented.

Note that although the real-world gap does not significantly alter the relative impact of the standards in terms of percent benefits, the absolute emissions are significantly higher when the real-world gap is factored into the analysis.

Figure 18 Summary results tab. Example for Mexico's passenger car fleet.

Ex-ante and Ex-post Evaluation of New Vehicle FE Standards

Country/Region	Mexico	Units
Vehicle fleet scope	Passenger vehicle (exluding light-trucks)	
Baseline year	2012	MY
Baseline new vehicle sales	630,913	-
Vehicle stock at baseline year	10,566,000	-
New vehicle CO2 emission - base	150.8	g/km
Regualated period	2012-2016	MY
Estimated future fleet growth rate	2%	-

EX-ANTE	Year	2020	2025	2030	2035	2040	2045	2050
CO2 impact BAU vs. Standard	BAU, MtCO2/year	28.1	29.9	32.3	35.3	38.8	42.7	47.1
	Standard, MtCO2/year	27.2	28.2	30.0	32.5	35.5	38.9	42.9
	% Reduction, Annual	-3.4%	-5.6%	-7.2%	-8.0%	-8.5%	-8.8%	-8.9%
Real-world GHG impact BAU vs. Standard	BAU, MtCO2/year	33.7	35.9	38.8	42.4	46.5	51.2	56.5
	Standard, MtCO2/year	32.6	33.9	36.0	39.0	42.6	46.7	51.5
	% Reduction, Annual	-3.4%	-5.6%	-7.2%	-8.0%	-8.5%	-8.8%	-8.9%
EX-POST								
CO2 impact BAU vs. estimated vs. ex-post	BAU, MtCO2/year	28.1	29.9	32.3	35.3	38.8	42.7	47.1
	Estimated, MtCO2/year	27.2	28.2	30.0	32.5	35.5	38.9	42.9
	Ex-post	27.1	28.1	30.0	32.5	35.5	38.9	42.9
	% Reduction, Annual	-3.7%	-5.9%	-7.3%	-8.1%	-8.6%	-8.8%	-8.9%
Real-world GHG impact BAU vs. Standard	BAU, MtCO2/year	33.7	35.9	38.8	42.4	46.5	51.2	56.5
	Estimated, MtCO2/year	32.6	33.9	36.0	39.0	42.6	46.7	51.5
	Ex-post	32.5	33.8	36.0	38.9	42.6	46.7	51.5
	% Reduction, Annual	-3.7%	-5.9%	-7.3%	-8.1%	-8.6%	-8.8%	-8.9%

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As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

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Programme/project description:
Advancing Transport Climate Strategies

Authors:
Francisco Posada, Zifei Yang & Kate Blumberg

Design:
Jenny Watkinson, Büro Watkinson, Berlin

Photo credits/sources:
Shutterstock

Printed on 100% recycled paper, certified to FSC standards.

Bonn, 2017