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Transport Emissions Analysis Methodology (TEAM)

Supporting Measurement, Reporting, and Verification (MRV) and Results-Based Climate Finance

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Executive Summary

Reducing greenhouse gas emissions from transport is essential for achieving national climate targets, yet the sector has lacked practical and credible tools to quantify the emissions impacts of policies in a way that supports monitoring, reporting, verification (MRV), and results-based climate finance. This report responds to that gap by presenting a robust, MRV-compatible methodology for analyzing transport emissions.

The report introduces a scenario-based transport emissions analysis methodology (TEAM) and model that quantifies emission reductions by comparing a measured WithPolicy scenario against a conservative and credible WithoutPolicy counterfactual. The methodology supports analysis both ex post, using observed data to measure achieved emission reductions, and ex ante, to assess the mitigation potential of proposed policies. The current application focuses on road transport—the largest source of transport emissions—while allowing for future expansion to other transport modes.

The analytical framework integrates vehicle fleet dynamics, transport demand, energy consumption, and emissions factors through a bottom-up approach calibrated to national fuel consumption data. This calibration ensures consistency with energy balances and strengthens the credibility of results for MRV and carbon-crediting applications. The model captures key drivers of emissions, including vehicle ownership, usage patterns, technology mix, and fuel types, while accounting for broader economic and demographic trends.

The methodology is designed to assess a wide range of transport policies, including vehicle efficiency and emissions standards, restrictions on used-vehicle imports, fuel pricing and subsidy reforms, vehicle scrappage programs, incentives for low- and zero-emission vehicles, and policies that promote modal shift and freight efficiency. It explicitly addresses additionality, baseline setting, leakage, and uncertainty, applying conservative assumptions where needed to safeguard environmental integrity.

By providing a transparent and scalable analytical tool, the methodology enables governments and development partners to strengthen transport MRV systems, prioritize high-impact mitigation policies, and improve access to results-based climate finance and carbon market mechanisms.

Abbreviations and Acronyms

BAU	Business as Asual
BEV	Battery Electric Vehicle
CCDR	Country Climate and Development Report
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
EU	European Union
Euro 1 to 6, I to VI	European New Vehicle Emission Standards
EV	Electric Vehicle
$g/kmCO_2$	Grams Of Carbon Dioxide Emissions Per Kilometer
GDP	Gross Domestic Product
GHG	Greenhouse Gas
Gt	Gigaton
$GtCO_2e$	Gigatons Of Carbon Dioxide Equivalent
HH	Household
IPCC	Intergovernmental Panel on Climate Change
km	Kilometer
MJ	Megajoule
MMHE	Mean Monthly Household Expenditure
MRV	Monitoring, Reporting, And Verification
NDC	Nationally Determined Contribution
PHEV	Plug-In Hybrid Electric Vehicle
PM	Particulate Matter
SUV	Sports Utility Vehicle
TCAF	Transformative Carbon Asset Facility
TRACE	Transport Research and Costing in Europe

1. Background and Rationale

The analysis presented here is against a backdrop of rapidly growing transport-related emissions on a regional as well as global scale, requiring urgent attention from policy makers.

Worldwide, transport emissions in 2024 reached 8.4 gigatons of carbon dioxide equivalent ($GtCO_2e$). Of this, road sector emissions were just over 6 $GtCO_2e$, 8 percent higher than in 2015. Emission growth averaged only 0.2 percent annually from 2019 to 2024, down from 1.7 percent per year between 2015 and 2019.

Regionally, transport-related emissions are increasing more rapidly in developing economies than in Europe or North America—a trend that is likely to continue in the coming decades.

Delivering on the updated Nationally Determined Contributions (NDCs) by 2030 would bring about a decline in emissions. However, the implied global emissions by 2030 still exceed, by a large margin, the emissions on pathways consistent with the Paris Agreement. Available evidence suggests that achieving NDC targets would require limiting transport-related CO_2 emissions to about 2–3 Gt by 2050.

On a global scale, there is a need for transport to match the ambition of other sectors, both to mitigate greenhouse gas (GHG) emissions and to maintain clear monitoring and documentation of the (potential) impacts of emissions. Meanwhile, a lack of methodological tools has hindered progress toward ambitions by making carbon financing a challenge for transport projects. In particular, there is an urgent need for monitoring, reporting, and verification (MRV)-compatible methods of evaluating, analyzing, and measuring the impacts of specific policies and interventions (both before and after implementation) that demonstrate benefits in terms of GHG emission reductions.

1.1 Methodology

The present report outlines an MRV-compatible method of evaluating, analyzing, and measuring the impacts of specific transport policies and interventions that deliver GHG emission reductions. The method may be applied either before implementation (ex ante), using projected estimates, or after implementation (ex post).

The current version of the methodology evaluates GHG emission reduction due to a shift in vehicle usage and fuel types in the largest contributing subsector: road transport. The methodology may be used to analyze:

- GHG emission reductions due to a specific intervention, following implementation and using measurable variables. This, ex post, evaluation method is the focus of the report.

- The potential impacts of different future policy scenarios on GHG emissions. This ex ante analysis can help select policies for evaluation in various countries by identifying their mitigation potential.

The analytical process is scenario based. A measured *WithPolicy* scenario (what happened) is compared against a modeled, conservative, and credible *WithoutPolicy* counterfactual scenario, which evaluates what would have happened had the policy not been enacted.

Need for ex post analysis

Ex post, the magnitude of change in transport sector emissions can be calculated using historical data and compared to a *WithoutPolicy* counterfactual scenario.

The Bank's lending operations—including investment project financing and development policy financing engagements—provide a substantial market for the evaluation of emission reductions due to vehicle and fuel policies. This analysis will, in turn, expand transport projects' access to results-based carbon financing and similar mechanisms.

Need for ex ante analysis

The methodology may also be used to estimate the GHG emission reductions that could be achieved by policy changes yet to be enacted.

One ex ante application is for the quantitative analysis of road vehicle and fuel interventions as required by Country Climate and Development Reports (CCDRs). The World Bank is investing in these country-level analytics to help identify the right policies, plans, and timelines for climate action specific to each country's local context and development challenges—and transport is recognized as one of the five critical sectors for a low-carbon transition.

Across the 93 CCDRs prepared as of November 2025,[1] improving transport infrastructure is highlighted as necessary for reducing GHG emissions, connecting people with jobs and services, improving air quality, and increasing productivity and competitiveness through better logistics.

The CCDRs for countries in East and West Africa, including Ghana, the G5 Sahel countries,[2] Angola, and Malawi, mention policies pertaining to imports of used vehicles (including fuel efficiency standards and age restrictions) and motorization management practices (including scrappage) for passenger cars. In East Asia and Pacific and also Latin America and the Caribbean, mitigation scenarios include fleet renewal for road freight trucks, improvements in logistics operations and cargo loading, incentive programs for alternative fuel vehicles (including e-mobility), and adoption of personal cars. Across the Middle East and North Africa, and Europe and Central Asia, there is an additional focus on national fuel standards and fossil fuel pricing reform.

The methodology presented here could be a valuable resource for current and upcoming CCDRs in identifying the most impactful vehicle and fuel policies and for articulating how they interact with other economic and sustainable development goals.

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1 See World Bank, "Country Climate and Development Reports (CCDRs)," https://www.worldbank.org/en/publication/country-climate-development-reports.
2 Burkina Faso, Chad, Mali, Mauritania, and Niger.

2. Implementing the Model

The modeling approach used to quantify emission reductions examines the effects of policies and regulations that modify the use of road transport, transport modes, technology employed, and the adoption of these technologies by end users, as well as energy demand. The model can estimate potential emission reductions from policies expected to be adopted, as well as those whose implementation is complete.

The transport sector is dynamic. There are many simultaneous interactions within the sector as well as other changes that affect transport activity and emissions (e.g., growth of gross domestic product [GDP], rural to urban migration, infrastructure development, and changes in vehicle fleets). A before-and-after comparison of business as usual (BAU) and specific projects cannot isolate and identify the impacts of specific policies.

The analytical process described herein uses an ex post, measured *WithPolicy* scenario (what happened) and a modeled, conservative, and credible counterfactual *WithoutPolicy* scenario. The *WithPolicy* scenario is compared to the *WithoutPolicy* scenario.

The scenarios will differ only in the implementation of specific policies or interventions. Thus, all activities that alter emission intensity and are outside the scope of an evaluated intervention, are included in the *WithProject* measured scenario and directly transferred to the *WithoutProject* counterfactual scenario. The comparison of the *WithPolicy* and *WithoutPolicy* scenarios quantifies the emission reductions that can be attributed to a policy's enaction.

The methodology is primarily meant for measuring, reporting, and verifying emission reductions achieved by recently adopted policies.

2.1 Overview: A continually evolving model and methodology

Like most analytical models, the model used for the present analysis and its methodology is continually evolving. So far, the model includes all road transport (e.g., passenger cars, motorcycles, three-wheelers, light-duty commercial vehicles, heavy-duty trucks, and buses). In its next stage, the model will incorporate rail (metro, light rail, suburban, and long distance) for passengers and freight.

The model includes an analytical framework to evaluate policy actions such as the choice of standards for vehicle technology, emissions, and fuel consumption; the incorporation of electric vehicles (EVs);

the evaluation of the enforcement (or tightening) of restrictions on the import of used vehicles; the removal of fuel subsidies; and the implementation of vehicle scrappage programs.

Other policy choices will be added to the framework as the demand arises. The modal choice for passengers and freight between road transport modes and rail will be further detailed.

Subsequent to this, adding waterborne (inland waterways and coastal) and air (regional and national) transport modes to the model could enable accounting for consumers' choices of other passenger and freight travel modes. This will inform dialogue on improvements at the level of transport systems and how these improvements impact GHG emissions at the country or subnational level. This allows an MRV-based evaluation of achievements that feed into distinct carbon crediting programs.

2.2 Key steps in applying the model

Define the modeling boundary

Geographical

A first step in applying the model is to set the modeling boundary. For countrywide policies, national borders can serve as the boundary. However, if a policy impacts only part of a territory—for example, vehicle activity in the metropolitan area of the capital city—a more limited area may be chosen. However, this will, in many cases, bring up issues of transboundary leakage. For example, commuters residing outside the area may contribute significantly to transport activity within the metropolitan area; the same goes for freight trucks making a drop-off.

Leakage must be dealt with by redefining boundaries, or estimated through an applied discount, where necessary.

Time period

The model is set up for conducting scenario-based analysis over a period of up to 31 years, with the first year being between 2010 and 2030. The analysis period must be divided into three parts:

- A historical period, from the base year, when the policy package was enacted, up to the most recent year for which data are readily available.
- A period before this base year, which will be used for evaluating tendencies before the policy package was enacted.
- A future period after the year for which most recent data are available to forecast future impacts of the enacted policy package over a crediting period.

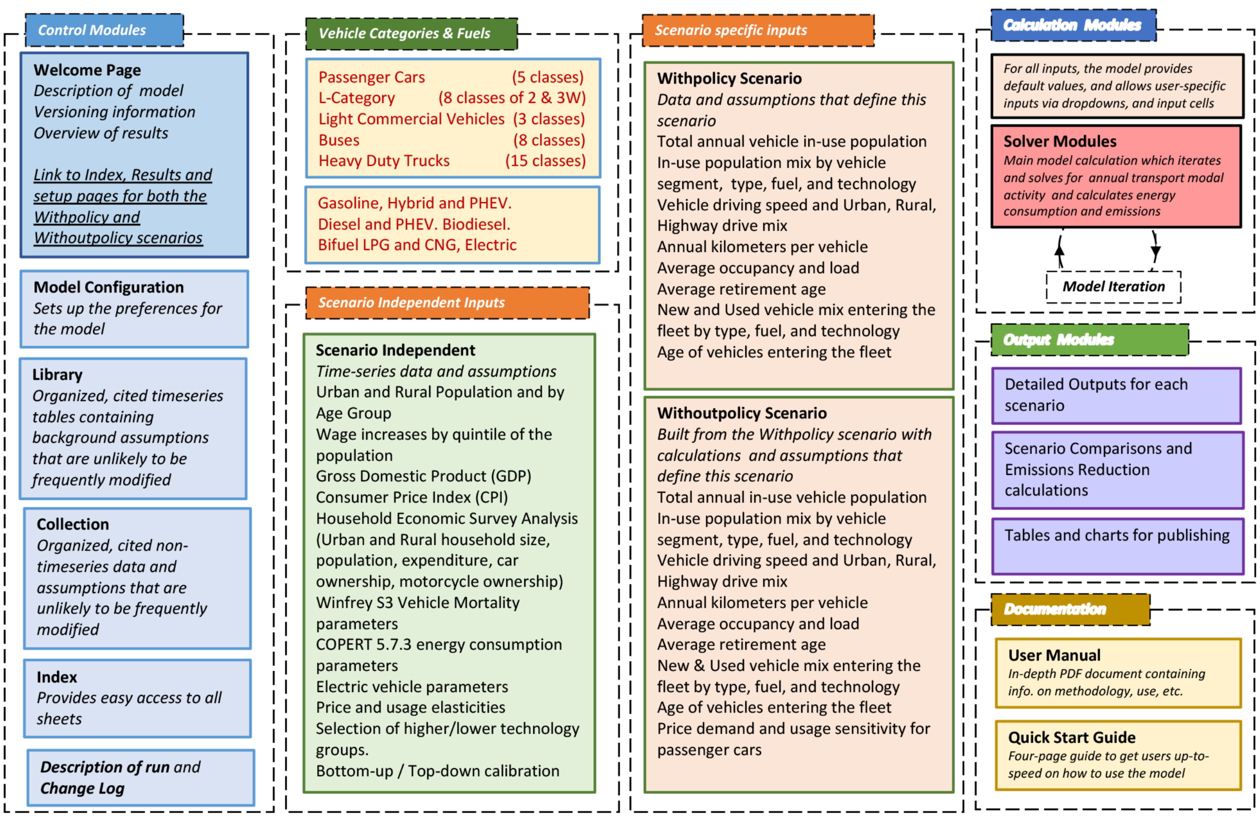
For example, suppose a policy package was enacted in 2017, the year for which most recent data are available is 2020, and the proposed crediting period is through 2030. The first year of the modeling framework could be 2010. This would give 2010–20 as the period for which historical data are available, and a forecasting period through 2040. The analysis from 2017 to 2020 would be results based (ex post), whereas from 2021 to 2030, the future value of policy actions would be forecast.

For results-based crediting, new data are introduced each year into the model (with a time lag dependent on data availability). Thus, for example, in 2023, data for 2021 may become available. These data are added to or updated in the model to calculate the emission reductions resulting ex post due to the policy package for 2021. In this way, the model records the outcomes of the MRV program annually. Based on this new information, the model also recalculates the forecast period (to 2040). The model will output data and results over any period that the user selects within these 31 years.

Build the modeling diagram

Once the modeling boundary has been selected, historical data are added in the tool for the *WithPolicy* operation and the tool is calibrated. As shown in figure 1, which illustrates the modeling diagram, there are two types of inputs: (1) scenario-independent inputs, which define the transport system within this framework; and (2) scenario-specific inputs in two groups, which distinguish the *WithoutPolicy* operation from the calculated *WithPolicy* operation. Specific data requirements are outlined in a later section. The first column of boxes in figure 1 ("Control Modules") indicates where each type of information is entered.

Figure 1. Modeling diagram



Note: CNG = compressed natural gas; LPG = liquefied petroleum gas; PHEV = plug-in hybrid electric vehicle; W = wheeler.

Define scenario-independent inputs

The scenario-independent inputs should ideally be publicly available data, so the tool can be used to share data and findings and build consensus across different groups of stakeholders. These data are stored on the model's "Library" and "Collection" pages. For data that have to be updated at a later date—via the MRV process mentioned earlier—the tool includes separate sheets for each data type. The updated data (and the reference sources cited for them) can be added to these sheets without affecting the initial load. This ensures data integrity and preserves a data chain of custody,[3] giving a complete and fully documented step-by-step history of the data and of the model users who have modified them.

Define scenario-specific inputs

The scenario-specific inputs are a mix of historical, measured data that define the *WithPolicy* drivers, and data and assumptions that will be used to creatively describe the *WithoutPolicy* drivers of the analysis.

For future years, the assumptions applicable to the *WithPolicy* operation and the *WithoutPolicy* counterfactual are defined and used as the basis for analysis.

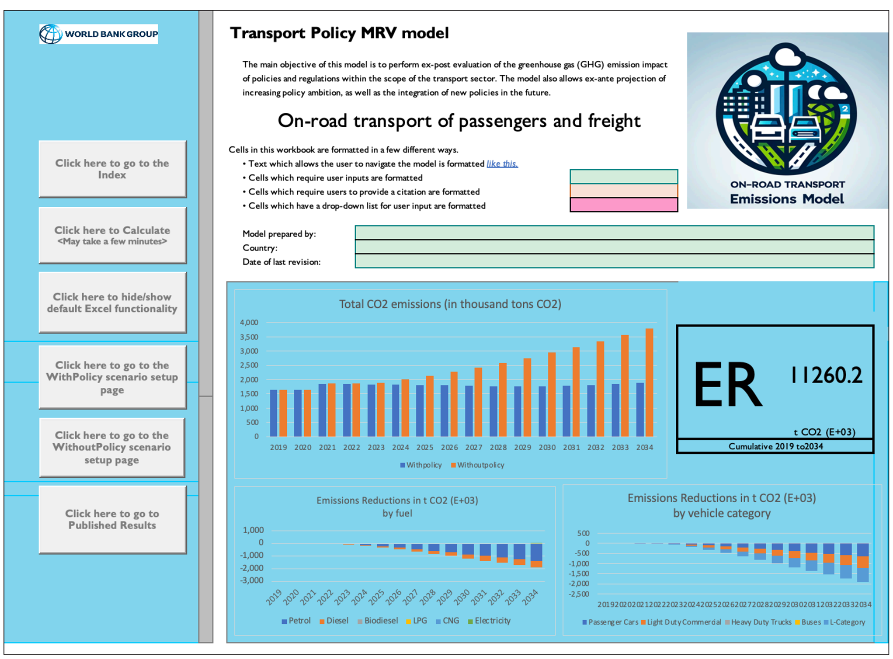
Understand the model layout

The model can be easily customized to specific analyses. It does not require enabling Microsoft Excel's default functionality and can be navigated using the built-in buttons and links. The model contains one Microsoft Excel workbook with (currently) 53 worksheets. All the sheets that are specific to a scenario end in "1" or "2" (the *WithPolicy* scenario or the *WithoutPolicy* scenario, respectively).

Model navigation is based on three sheets. The model's welcome page (figure 2) gives easy access to setting up the *WithPolicy* and *WithoutPolicy* scenarios, running the calculations, and accessing the results.

The setup pages for the *WithPolicy* scenario (Scenario 1) (figure 3) and the *WithoutPolicy* scenario (Scenario 2) (figure 4) provide links to all necessary sheets.

Figure 2. Welcome page of the model



Note: CNG = compressed natural gas; ER = emission reduction; LPG = liquefied petroleum gas; MRV = monitoring, reporting, and verification; tCO_2 = tons of carbon dioxide.

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[3] A process that tracks the movement of evidence through the collection, safeguarding, and analysis stages of its life cycle by documenting each person who handled the evidence, the date/time it was collected or transferred, and the purpose for the transfer.

Figure 3. Setup page for the *WithPolicy* scenario (Scenario 1)

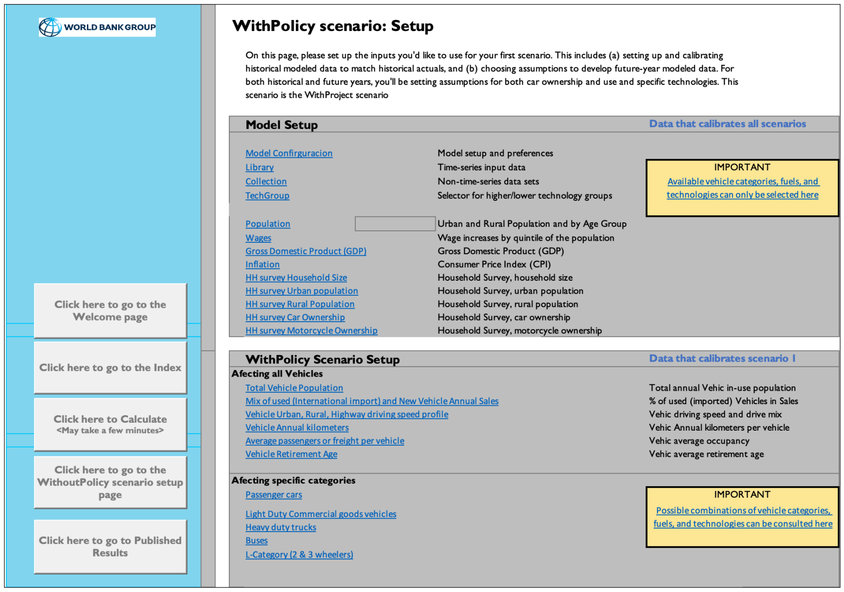
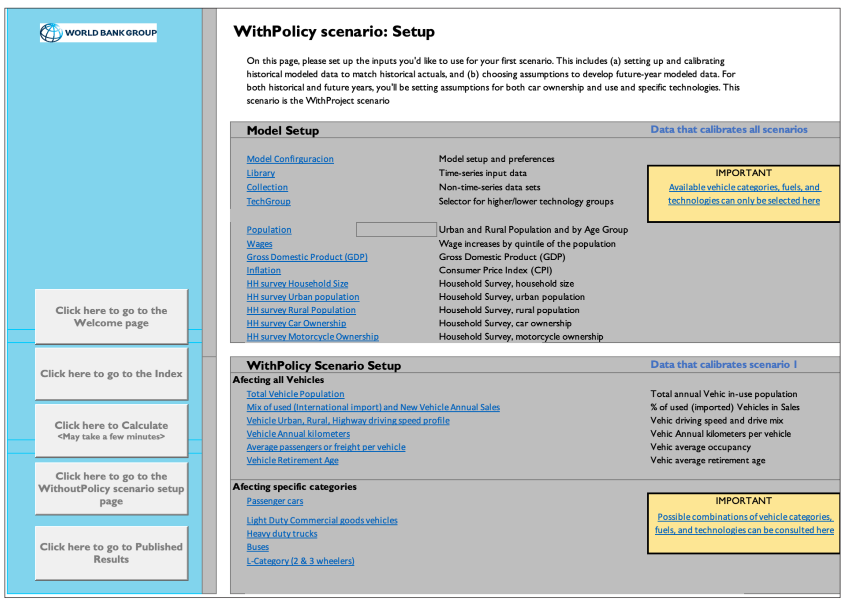


Figure 4. Setup page for the *WithoutPolicy* scenario (Scenario 2)



All sheets can be easily accessed via the "INDEX" sheet, which indicates what sector or scenario each sheet applies to and whether a sheet contains user input data.

Initial data are stored in the "Library" and "Collection" sheets. Each variable has a specific sheet so that the user can easily update numbers from one year to the next (in accordance with their MRV program) and cite the source of each update, to maintain adequate control. These variable-specific sheets also make it easy to use the model to evaluate the likely impact of different policy packages.

The model has results sheets and charts that the user can easily adjust to any output period (while the model calculates from 2010 to 2040, the user can select different subperiods within this range [e.g., 2017–27] for reports in the "Publish" sheet).

Analyze impact channels

The methodology and model are structured to evaluate different policy and regulatory impact channels, such as:

- Regulation of vehicles, for example, fuel efficiency standards, age restrictions, and technology standards applied to imports of new and used vehicles.
- Fossil fuel pricing reform (including but not limited to subsidy removal) and carbon taxes.
- Monetary or nonmonetary incentives for the purchase and use of newer, cleaner vehicles, including vehicle scrappage programs.
- Pricing of vehicle ownership.
- Pricing of vehicle use, for example, road pricing.
- Accelerated adoption of low-emission vehicles and clean transport modes.
- Improvements in infrastructure and services as alternatives to road-based travel to reduce the need to travel and encourage a modal shift, including investments in public transit and active mobility.

Typical policy actions that may be included in the model are listed in table 1.

Table 1. Examples of policy actions that are considered in the analysis

Policy	Type of policy	Type of intervention		
		Avoid	Shift	Improve
Efficiency and emissions standards for new and imported secondhand vehicles (including import restrictions)	regulation			X
Strict efficiency and emissions standards for new vehicles (including phase-out of new ICE vehicles)	regulation			X
Vehicle feebate system based on emissions	pricing			X
Vehicle special sales tax	pricing			X
Vehicle quota systems	regulation, pricing	X	X	X
Reduction in maximum age of in-use vehicles (including scrappage programs)	regulation, pricing			X
Vehicle registration fees based on emissions (including CO_2)	pricing			X
Cross-funded subsidies that promote the purchase of zero-direct-emission noncommercial vehicles	pricing			X
Incentives that promote the use of zero-direct-emission vehicles in commercial vehicle fleets	regulation, pricing			X
Pricing policies that favor usage of zero-direct-emission noncommercial vehicles	pricing			
Vehicle usage permits based on emissions (including CO_2)	regulation, pricing		X	X
Modal shift to mass transport	regulation		X	
Usage of larger capacity trucks	regulation, pricing		X	X
Distance-based vehicle insurance and registration fees	pricing			X
Congestion or low-emission zone charging	pricing	X	X	
Parking restrictions and pricing	pricing	X	X	

Note: CO_2 = carbon dioxide; ICE = internal combustion engine.

Example of an impact channel

An impact channel is a pathway between an intervention and its outcomes (and, eventually, its impacts). The example below illustrates how an impact channel is analyzed. A European Union (EU) regulation entered into effect on January 1, 2020, which sets fuel efficiency and emissions standards for new and imported secondhand vehicles (the standard includes a regulation on import age restrictions).

This policy package would have two impact channels, outlined as follows.

***WithPolicy* scenario**

1. **New vehicles.** All new vehicles sold after January 1, 2020, must meet the EU 2015 Euro 6 emission standard and the EU 2020 CO_2 emission standard (95 percent compliance in 2020 with an emission standard of 95 grams of carbon dioxide emissions per kilometer [g/km CO_2] and 100 percent compliance from 2022 onward). Motorcycles would be expected to comply with the Euro 5 standard. In future years, these standards will evolve to keep pace with EU standards.
2. **Imported secondhand vehicles.** All imported secondhand vehicles sold after January 1, 2020, must meet the EU 2015 Euro 6 emission standard and the EU 2015 CO_2 emission standard (130 g/km CO_2). In future years, these standards will change to maintain a gap of five years with EU standards for new vehicles.

***WithoutPolicy* scenario**

Continuation of the previous policy (which, in this case, we are assuming to be):

1. A requirement for all new vehicles to meet Euro 3 emission standards, though there are no CO_2 standards.
2. A requirement for all imported used vehicles to be under 15 years old, though there are no emissions or CO_2 requirements.

Note that in both cases, the regulation does not affect vehicles that are already in use. It only affects the new and secondhand vehicles entering the fleet each year, which slowly modifies the fleet mix every year based on (1) the vehicles in active service, (2) those leaving the active fleet each year, and (3) new and used vehicles entering the fleet each year. The resale of vehicles within the analytical boundary of the model does not affect the total active population: only new and used vehicles entering the fleet from outside the boundary impact the total active fleet. The analysis must consider the used vehicles entering the market that may comply with standards different from those for new original equipment manufacturer sales.

Vehicles may leave the fleet due to scrappage or disuse due to issues related to maintenance, parts, and reliability; or because they are being sold outside the analytical boundary (to another state, for example).

Logic flow

For the WithPolicy scenario

Apply the new policy starting January 1, 2020. The outcome can be measured. Future years are estimated to be able to assess the overall value of the program, but these estimates are not used for crediting purposes.

For the WithoutPolicy scenario

Suppose it can be shown that the new policy package increased the sales price of new or used vehicles. Then the demand for passenger cars in the *WithoutPolicy* scenario will be higher than that measured in the *WithPolicy* scenario. This will increase annual sales volume, and the distribution of used car imports by model year will change.

For private motorized transport (passenger cars and motorcycles), the calculations for the in-use fleet and sales are carried out in two parts (for each vehicle category and segment):

Vehicle population = Vehicles owned by households + vehicles owned by ministries, corporations, and others:

- **Vehicles owned by households.** This is derived from data from household (HH) expenditure surveys (cars and motorcycles per thousand population vs HH income). Any price change shifts the curve down, increasing ownership in the *WithoutPolicy* scenario.
- **Vehicles owned by ministries, corporations, and others.** The conservative estimate is inelastic but may vary from country to country (based on change in GDP, for example)

The profiles of vehicles entering the fleet will follow the prior logic outlined in the *WithoutPolicy* scenario. New vehicles with the current year as the model year continue to join the fleet, but local emission standards are more flexible and CO_2 standards are less stringent.

Older used vehicles enter the market meeting age law, only with higher local and CO_2 emissions.

Figure 5. Typical Gompertz curve

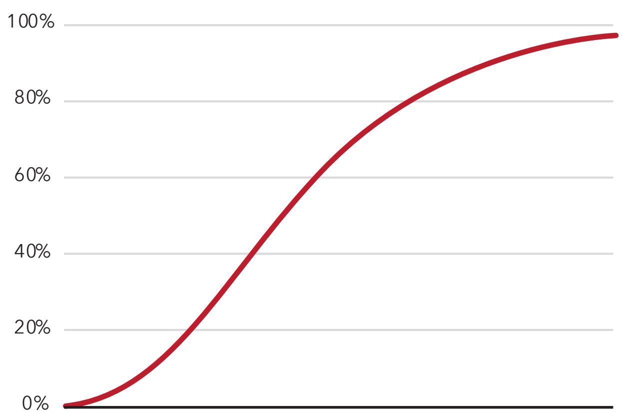
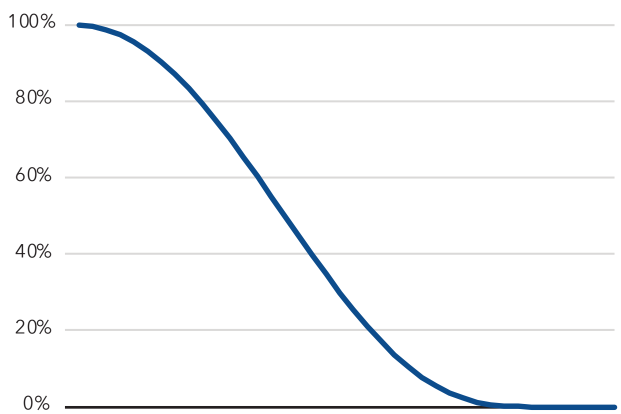


Figure 6. Mortality curve



Note that the average life of a vehicle is defined as the time point at which 50 percent of the original number of vehicles are no longer in service. For example, an average life of 15 years means that of 100 vehicles in service in year 0, only half (50) are likely to be in service at year 15 and very few at year 30. Buying a vehicle that has been serviced earlier does not extend this total life. So, importing older vehicles (in the *WithoutPolicy* scenario) will increase future scrappage and replacement volumes to stabilize the overall population.

Equation 1

$$Population_{year\ 1} = Population_{year\ 0} - Scrappage_{year\ 0} + vehicles\ \_entering\_fleet_{year\ 0}$$

Where in each category and segment:

$Population_{yearx}$ = The total in-use fleet of vehicles in year X.

$Scrappage_{yearx}$ = The number of vehicles leaving the in-use fleet in year X, due to scrappage or disuse due to issues related to maintenance, parts, and reliability; or due to the vehicles being sold outside the analytical boundary (to another state, for example).

$vehicles\ \_entering\_fleet_{yearx}$ = The number of vehicles entering the in-use fleet within the analytical boundary in year X. These will include new vehicles sold through the vehicle manufacturer's dealers, and new and used vehicles imported from outside of the analytical boundary (bought in another state, for example).

Suppose the types of vehicles demanded by users change over time (e.g., as users demand more mini and small cars in India, medium and luxury cars in China, or more sports utility vehicles [SUVs] in the Philippines), the historical data used to define the *WithPolicy* scenario will reflect this change and they will be transferred to the *WithoutPolicy* scenario.

However, suppose the *WithPolicy* scenario shows a shift to EVs, for example; the *WithoutPolicy* scenario will likely not have this shift or will have a slower change because there is no fuel efficiency regulation, and the expected vehicle technology is, for example, only Euro 3.

The average kilometers traveled per year by a vehicle varies by the vehicle's age, though this is more a function of the vehicle owner than of the vehicle itself (presuming that persons with higher disposable income tend to have higher mobility and own newer vehicles). The reduction in the average age of imported vehicles due to the regulation is therefore unlikely to have a primary impact on the kilometers traveled per year. However, EV adoption may have an effect if users are reluctant to use them on longer trips but prefer them for shorter trips.

Thus, the modeled *WithoutPolicy* scenario could have a more extensive fleet than the *WithPolicy* scenario (defined in [1] above), though with annual mileages that may be subject to adjustment and shorter in-use active life (defined in [2] above). The class mix of new and used vehicles entering the fleet in the *WithoutPolicy* scenario would be similar to that under the *WithPolicy* scenario. Still, the technology (and corresponding fuel economy) of the new and used vehicles entering the fleet in the *WithoutPolicy* scenario could be older (and lower).

With these data and assumptions, vehicle activity, fuel consumption, and emission for each vehicle type, technology, and age will be calculated for each scenario. The differences between the two scenarios would be due to the impact channels analyzed.

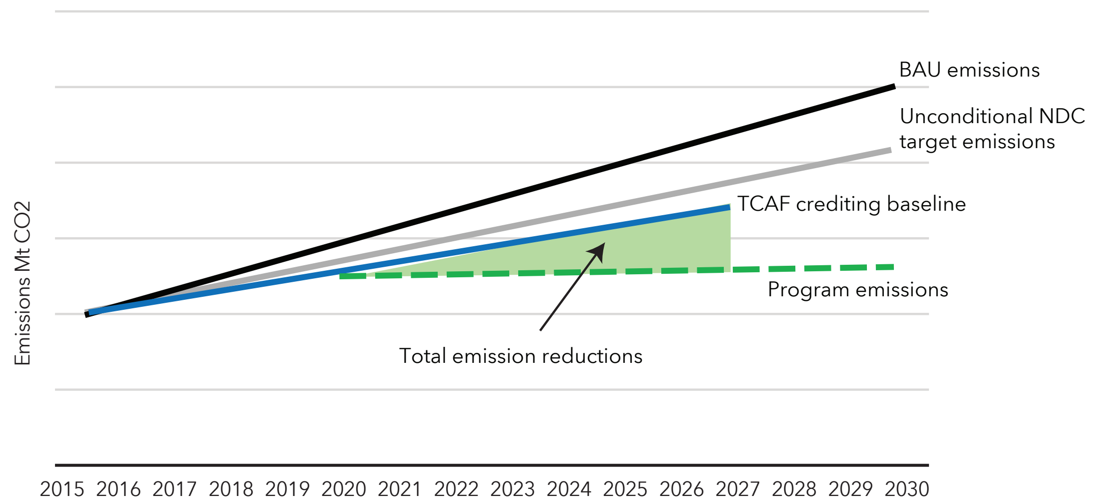
Account for additionality in calculations

GHG emission reductions can be counted only if they are *additional*. That is, if they would *not* have occurred without the policy or measure being enacted. Had reductions occurred anyway, without causality, then they are not additional.

Also, country signatories of the Paris Agreement formally agreed to reduce their GHG emissions and strengthen their commitment over time. Most developed, high-income countries committed themselves to an emission reduction target in absolute terms over an earlier year. Developing countries typically commit to an *unconditional* target or emission intensity they can achieve on their own, and offer to meet a stricter goal *conditional* on receiving international technical or financial assistance. Emission reductions required to meet NDC targets but committed to as part of the unconditional pledge would not be considered additional and should be part of the baseline.

Since emission reduction units that have been sold cannot be applied to future more ambitious commitments, the crediting baseline should be more conservative than the unconditional NDC target. This is to ensure a high level of environmental integrity and compensate for uncertainties in the process of determining and calculating emission reductions (see figure 7).

Figure 7. TCAF approach to crediting baseline

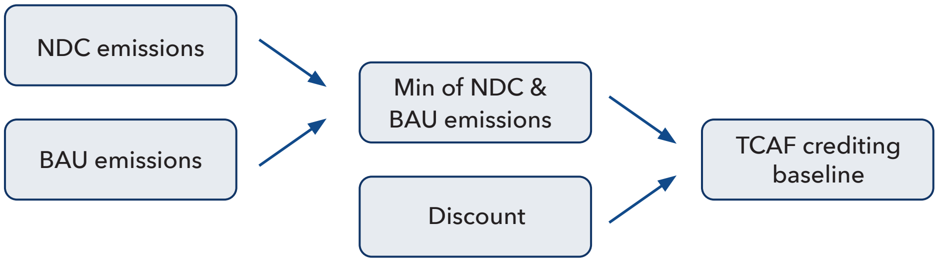


Note: BAU = business as usual; NDC = Nationally Determined Contribution; TCAF = Transformative Carbon Asset Facility.

If any other project-based emission reductions are sold (e.g., from a project-based mechanism such as Article 6.4 under the Paris Agreement), then these would have to be subtracted from the emission reductions credited to the program. In practical terms, this means the Transformative Carbon Asset Facility (TCAF) will make payments against a crediting threshold (or "TCAF baseline") that could be below the BAU emission trajectory and typically below the target emission trajectory. Single-year targets will conservatively be broken down to a trajectory of annual targets, with the default being linear interpolation to the 2030 goal.

Setting a conservative TCAF baseline may require applying a case- and country-specific discount to the calculated emission reduction (figure 8).

Figure 8. Process for calculating TCAF crediting baseline



Note: BAU = business as usual; Min = minimum; NDC = Nationally Determined Contribution; TCAF = Transformative Carbon Asset Facility.

It may be necessary to define and agree on three scenarios—BAU emissions, NDC unconditional emissions, and the crediting threshold—and calculate the emission reduction between the *WithPolicy* scenario and each of these three scenarios.

Suppose another co-financing mechanism is involved or policy implementation receives financial support from other sources (e.g., it is included in a policy lending operation), the calculated emission reduction must be attributed to the funding sources or partners. This attribution would be processed outside the model based on the model's results.

The difficulty in determining additionality is that activities reducing GHG emissions occur all the time. Vehicle fleets continually grow, and vehicles become more efficient as technology evolves. Changes in passenger and freight travel choices are driven by convenience, cost saving, and time saving, with little concern for GHG emissions. Other shifts occur due to structural social and economic changes or other technological and good-practice changes driven by regulatory, policy, and market forces.

This precludes trying to evaluate GHG emission reductions by comparing the emission intensity at one point in time against a baseline emission intensity at a previous point in time. Over the intervening period, there are likely to be many different activities that change emissions intensity and are beyond the control of the policy or other measure being evaluated.

An analysis of the barriers impeding the implementation of specific policies and measures can help prove the additionality of GHG emission reductions. These barriers may include:

- **Local traditions.** Lack of knowledge of practices, laws, customs, and market conditions may have prevented a more GHG-efficient scenario from being implemented.
- **Social barriers.** Societal actors may exert pressure to continue the status quo.
- **Financial barriers.** Implementation of specific policies and measures may require funding that would not be available without demonstrating a reduction in GHG emissions. This may include an investment feasibility analysis to determine whether a given policy or intervention is most likely to attract funding.
- **Institutional and political barriers** include lack of enforcement or political support for implementing policies and measures to reduce GHG emissions (e.g., the NDCs to the Paris Agreement).
- **Technological barriers.** A sector may lack access to the materials, equipment, or infrastructure necessary to implement a specific policy or measure. So, if this policy or measure were not to be enacted, the BAU scenario would result in higher emissions.

3. Conducting the analysis

Vehicular CO_2 emissions cannot be measured directly. They are calculated based on vehicle activity. Different vehicles (e.g., small, medium, and large passenger cars) have different fuel economy and emission characteristics, that must be accounted for. The basis of this bottom-up methodology is shown in figure 9.

Figure 9. Basis of the bottom-up methodology

Number of vehicles	X	Usage (km/yr)	X	Energy consumption (MJ/km)	X	Emissions factors (g CO_2/MJ)

Note: g CO_2 = grams of carbon dioxide; km = kilometer; MJ = megajoule; yr = year.

Where:

- **Number of vehicles** is subdivided by category, segment, fuel and technology, and emission standard.
- **Usage.** Average travel speed and annual mileage are in three usage bins (urban, rural, and highway).
- **Energy consumption factors** for each combination of vehicle type are calculated using COPERT 5.7.3.
- **Emission factors** in gigatons of carbon dioxide (GtCO2) per megajoule (MJ) for each fuel are calculated using local values or default values from the Intergovernmental Panel on Climate Change (IPCC).

3.1 Calibration: Bottom-up to top-down

Since gasoline is almost exclusively used in road transport and national-level gasoline consumption is reported by countries in their energy balances (and by the International Energy Agency), these data can be used to calibrate the bottom-up calculations to top-down data. This energy consumption adjuster, which matches the bottom-up gasoline consumption of the entire in-use vehicular fleet to top-down consumption, is applied to all vehicle activity independent of the fuel used.

Applicable international emission factors from the COPERT database are adjusted. While the need for this adjustment could be due to operating and maintenance practices in the countries in question, it is also likely due to needed fine-tuning of the annual vehicle use (kilometers/year) estimates or slight differences in the vehicle urban/rural/highway speed profiles.

Number of vehicles

Since the MRV analysis is ex post, based on actual results, the number of vehicles sold annually within the modeling boundary for each category and vehicle segment in the *WithPolicy* scenario needs to be recorded (see table 2 for a list of common categories).

The number of vehicles sold annually is calculated for the *WithoutPolicy* (baseline) scenario also. This calculation will depend on the specific policies being enacted. If policy entails the use of higher-capacity trucks, then the *WithoutPolicy* scenario (with smaller trucks) would need a more significant number of vehicles to have the same carrying capacity as the *WithPolicy* scenario. If policy introduces the sales of EVs instead of internal combustion engine alternatives, then the essential substitution would be one-for-one. Suppose the policy change entails a slight difference in end-user vehicle cost between the two scenarios, in that case, an agreement must be reached on the demand price elasticity of sales to be applied. If the *WithoutPolicy* scenario results in higher-cost vehicles, then this may result in lower uptake of vehicles. Conversely, if vehicles are less costly to users under the *WithoutPolicy* scenario, then this may result in higher uptake.

The notion of elasticity adopted in the model is based on an econometrics study of the price elasticity of vehicle demand in the absence of country-specific data. The adopted elasticities, derived from meta-analyses, have been adjusted considering sectoral and country contexts. The more conservative short-term elasticities are typically considered for the possible program lifetime. Of course, these should be used if credible country-specific elasticities are available.

Under most circumstances, car and motorcycle purchases for household transportation are price sensitive, although purchasers do not look to only optimize transport cost. A combination of needs, budget, desired features, the competition's offerings, safety, fuel economy, and brand preferences could be more critical. While the model applies elasticities to the purchase of cars for household transportation, it generally considers that the price-demand elasticity for commercial vehicles is basically inelastic. However, this can be changed according to the policy package being evaluated.

Table 2. Vehicle categories and segments used in the model

Vehicle category
Passenger cars
Light commercial vehicles
Buses
Heavy trucks
Motorcycles and 3-wheelers

Buses by segment
Urban buses, midi <=15 t
Urban buses, standard 15 - 18 t
Urban buses, articulated >18 t
Coaches, standard <=18 t
Coaches, articulated >18 t

Passenger cars by segment
Mini
Small
Medium
Large, SUV, luxury

Light commercial vehicles by segment
N1-I
N1-II
N1-III

Motorcycles and 3-wheelers by segment
Mopeds 2-stroke <50 cm^3
Mopeds 4-stroke <50 cm^3
Motorcycles 2-stroke >50 cm^3
Motorcycles 4-stroke <250 cm^3
Motorcycles 4-stroke 250 - 750 cm^3
Motorcycles 4-stroke >750 cm^3
Quad 3W & ATV
Micro car

Heavy trucks by segment
>3,5 t
Rigid <=7,5 t
Rigid 7,5 - 12 t
Rigid 12 - 14 t
Rigid 14 - 20 t
Rigid 20 - 26 t
Rigid 26 - 28 t
Rigid 28 - 32 t
Rigid >32 t
Articulated 14 - 20 t
Articulated 20 - 28 t
Articulated 28 - 34 t
Articulated 34 - 40 t
Articulated 40 - 50 t
Articulated 50 - 60 t

Fuel and technology
Petrol
Petrol hybrid
Petrol PHEV
Diesel
Diesel PHEV
LPG bifuel
CNG bifuel
BEV

Emissions standard
Conventional
Euro 1/I
Euro 2/II
Euro 3/III
Euro 4/IV
Euro 5/V, V+
Euro 6/ VI A/B/C/D/E
Electric

Note: 3W = three-wheeler; ATV = all-terrain vehicle; BEV = battery electric vehicle; cm^3 = cubic centimeter; CNG = compressed natural gas; LPG = liquefied petroleum gas; PHEV = plug-in hybrid electric vehicle; SUV = sport utility vehicle; t = ton.

Usage

Emissions and fuel consumption per vehicle depend on the distance a vehicle travels and can vary significantly depending on the vehicle's speed. Thus, the annual distance traveled, which will vary by vehicle type and age and the percentage of this travel that occurs on an urban street or rural highway, along with the average travel speed in each environment, needs to be entered into the model.[4]

[4] From the COPERT "Average speed" emission model.

However, sensitivity is low because of the bottom-up to top-down calibration. If annual mileage were to be increased, the resultant correction factor would reduce.

This information can be obtained from:

- A traffic simulation model (e.g., VISSUM, EMME2),
- A survey (e.g., the Gas Station Survey), or
- Expert opinion.

In future years, vehicle travel time may change when increased mobility and vehicle usage can impact the typical congestion level and average speed.[5]

Another way of obtaining speed estimates from road users is via a level of service estimate, as shown in table 3.

Table 3. Relationship between service level and speed, by type of road

Road type	Level of service	Speed/Limit
Motorway–national		
	Freeflow	>0.91894
	Heavy	0.78231–0.91894
	Saturated	0.38413–0.78230
	Stop + go	<0.38413
Motorway–city		
	Freeflow	>0.93746
	Heavy	0.82821–0.93746
	Saturated	0.49121–0.82820
	Stop + go	<0.49121
Trunkroad/primary–city		
	Freeflow	>0.87848
	Heavy	0.75303–0.87848
	Saturated	0.45306–0.75302
	Stop + go	<0.45306
Distributor/secondary		
	Freeflow	>0.80333
	Heavy	0.66006–0.80333
	Saturated	0.41766–0.66005
	Stop + go	<0.41766
Local/collector		
	Freeflow	>0.82409
	Heavy	0.65358–0.82409
	Saturated	0.42271–0.65357
	Stop + go	<0.42271
Access–residential		
	Freeflow	>0.96347
	Heavy	0.81352–0.96347
	Saturated	0.57726–0.81351
	Stop + go	<0.57726

Source: The "traffic situation" model from Mario Keller, *Handbook Emission Factors for Road Transport 3.1: Quick Reference* (Bern: INFRAS, 2010), https://cdn.prod.website-files.com/6207922a2acc01004530a67e/64dbb2e9c9e37c80513e0a4b_HBEFA31_Help_en.pdf.

[5] Average speed in this context equals the distance traveled divided by the travel time and is expressed in kilometers per hour.

Annual vehicle use may differ between the *WithPolicy* and *WithoutPolicy* scenarios. For example, when passengers switch to buses for commuting, this is unlikely, in many cases, to affect their vehicle ownership but can directly impact the annual use of their vehicles. Similarly, end users who decide to purchase an EV instead of an internal combustion engine vehicle may limit its use for longer journeys.

Ridership/load factor

The relationship between vehicle-kilometer and passenger-kilometer or freight-ton-kilometer traveled is required when the model evaluates modal shift between travel options.

Information to analyze this relationship can be collected from:

- Origin-destination (O-D) surveys,
- Other surveys (e.g., the Gas station Survey), or
- Expert opinion.

Energy consumption

The MRV methodology uses COPERT's empirically derived emission factors to model energy consumption when local figures are not available. Each emission factor in COPERT is a function of the average vehicle speed. This emission factor has been derived using mathematical regression based on experimental data when driving under real-world conditions. The MRV methodology currently uses COPERT version 5.7.3, which was published by EMISIA for the European Environmental Agency in January 2024 and includes updates to previous versions.

COPERT is used to model vehicular energy consumption and all criteria pollutants.

CO_2 emission factors

CO_2 emissions are modeled from the energy consumption for each fuel. When local figures are not available, default values are used from IPCC's "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" (https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_3_Road_Transport.pdf).

3.2 Preliminary analytical steps

Set the baseline

Defining and building agreement around the counterfactual *WithoutPolicy* baseline for emission reduction crediting can be complex. Since the emission reduction that can be reported is the difference between the *WithPolicy* and *WithoutPolicy* scenarios, setting this baseline has a direct impact on the emission reduction. It is a balancing act to demonstrate that the resultant emission reduction is sufficiently conservative while not disadvantaging the host country. The basis for defining the transport activity likely to have been implemented without a given policy package must follow a rationale acceptable to all stakeholders.

There will always be changes in GHG emissions that are not captured by the definition of the *WithPolicy* and *WithoutPolicy* scenarios. These emissions will be treated as leakage and are held constant between the two scenarios.

Perform scenario calculations

The model performs the scenario calculations based on the following approach.

First, the model analyzes the change in vehicle ownership and use together with changes in transport demand from the policy package being evaluated in this analysis (e.g., the implementation of emission and fuel economy standards for new vehicles). As historic data under the *WithPolicy* scenario include the impact of these changes, the counterfactual *WithoutPolicy* scenario is modified to represent what would most likely have happened had the policy package not been enacted. While part of this change will be deterministic (a new obligatory standard is brought into force), it could, for example, change the price of vehicles or other characteristics that affect the end-user's choice.

When vehicle prices or other characteristics influencing end-users' choice are altered, the demand adjustment is determined by analyzing the price (or time) effect by employing the most rigorous possible of the following approaches:

a) Time-series econometric analysis
b) Panel econometric analysis
c) General equilibrium analysis
d) Adopting robust estimates from the literature

The model is set up to use approach (d) in the understanding that other more rigorous methods will be applied whenever possible. There are cases, however, when the end-user choice does not respond to variable cost, or it is difficult to define the response. In these cases, choice elasticity may not be applied, and this can result in a more conservative emission reduction, although this has to be substantiated. This is treated in more detail later in this report's discussion of transport demand.

The between-scenario difference in vehicle ownership, use, and energy demand can be analyzed through the various impact channels. Before the model can produce results, it should be calibrated to local conditions using the energy balance method as described later.

After analyzing the change in vehicle ownership and use and changes in transport demand from the policy package under consideration, the model determines the end-user energy consumption by fuel and emissions for the *WithPolicy* and *WithoutPolicy* scenarios in the base year, subsequent (historical) years, and—ex ante—in future years through the end of the modeling period.

- Any constraint on energy supply by fuel type should be applied.
- Any additional energy supply needed to meet the demand for operation in future years should now be defined. Since energy demand in the *WithoutPolicy* scenario is likely higher, additional capacity may be required.

The emission differences between the two runs has to be evaluated now. The results-based emission crediting is informed by the (ex post) analysis based on historical data within the confines of the different baselines. At the same time, the recalculation of the (ex ante) forward-looking estimate reevaluates the expected total value of the program.

Additionally, enacting the policy package under consideration may generate a net cash flow difference between the *WithPolicy* and *WithoutPolicy* runs. This additional free cash flow could be utilized for other improvements to the transport system that yield further GHG emission reductions. For example, this would be the case when a fossil fuel subsidy reform is used to improve public transport. This can be identified in a separate impact channel and increase the calculated emission reduction from the enactment of the policy package.

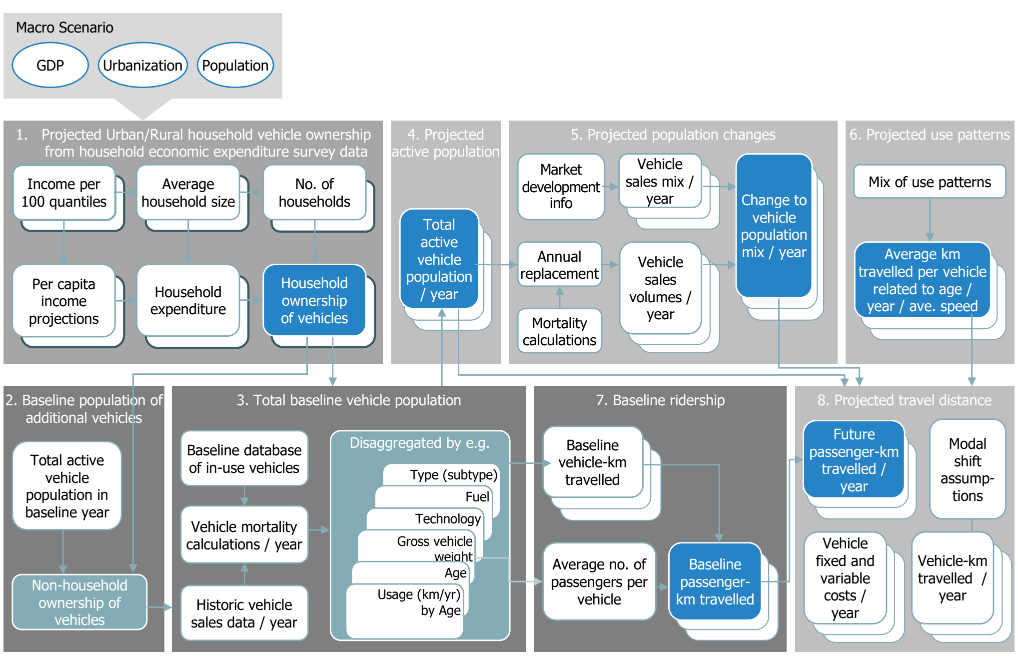
3.3 Analytical framework

The analytical framework for road vehicles is shown across figures 10–13 in four groups. The figures contain descriptions of each step within the respective groups:

a) Passenger cars and two-wheelers (figure 10)
b) Mass passenger transport (buses and coaches) (figure 11)
c) Freight transport (light commercial vehicles, medium- and heavy-duty trucks, and tractor-trailers) (figure 12)
d) Efficiency and emissions (for all vehicles) (figure 13)

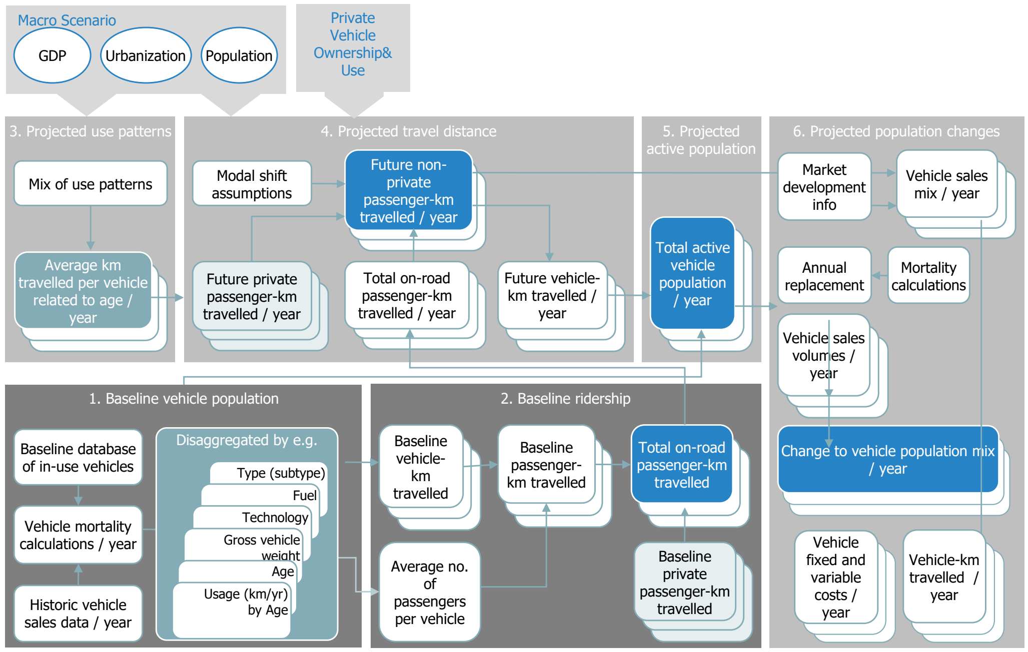
At a later stage, rail (metro, suburban, intercity, and high-speed rail), waterborne (inland waterways and coastal shipping), and air (national and regional aviation) may be added to the model.

Figure 10. Passenger cars and two-wheelers



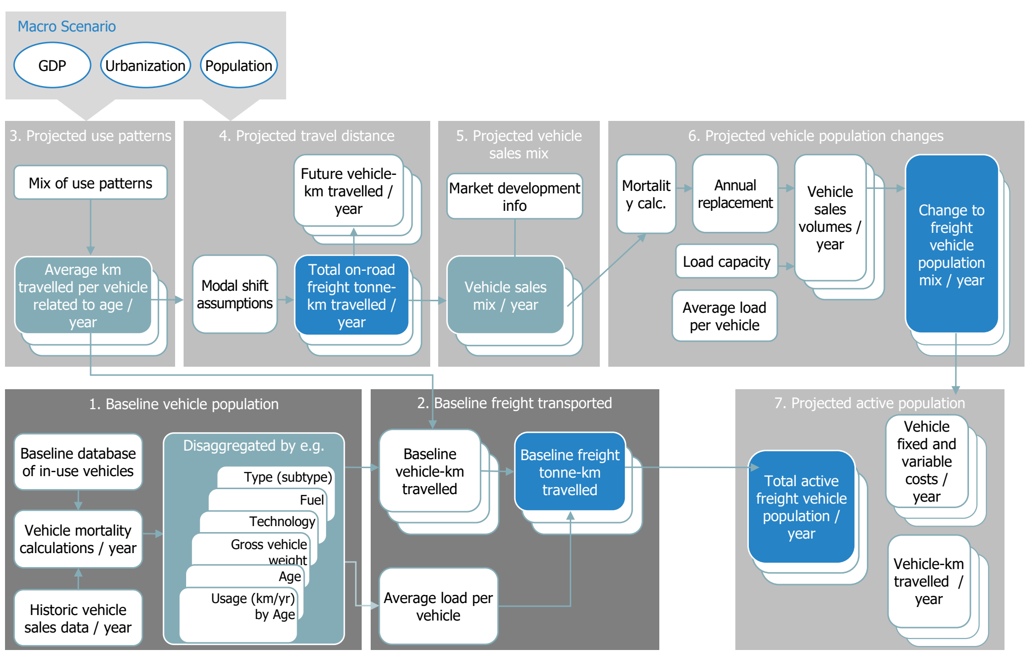
Note: GDP = gross domestic product; km = kilometer; yr = year.

Figure 11. Mass passenger transport (buses and coaches)



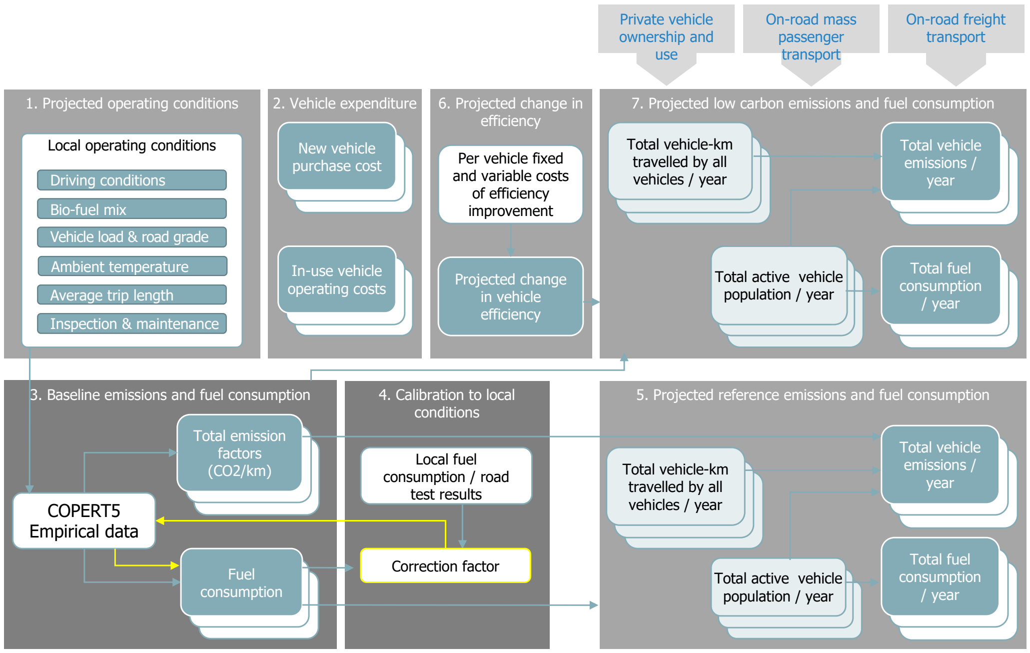
Note: GDP = gross domestic product; km = kilometer; yr = year.

Figure 12. Freight transport (light commercial vehicles, medium- and heavy-duty trucks, and tractor-trailers)



Note: GDP = gross domestic product; km = kilometer; yr = year.

Figure 13. Efficiency and emissions (for all vehicles)



Note: CO_2 = carbon dioxide; km = kilometer.

Analyze passenger car and motorcycle ownership

The steps in this section refer to figure 10.

Forecast vehicle ownership

Forecast vehicle ownership using HH survey data (refers to figure 10, step 1).

The World Bank has supported HH surveys in client countries for many years. External users can download the data from the 129 Living Standards Measurement Study surveys from the World Bank's "Living Standards Measurement Study (LSMS)" (https://microdata.worldbank.org/index.php/catalog/lsms).

Each Living Standards Measurement Study survey has data on vehicle ownership, including of cars and motorbikes, as well as data on HH size and expenditure, which can be used to estimate future growth in the private motorized vehicle fleet using the methodological steps given further below. Note that each "typical" household in the survey has an associated weight. Households have been assigned weights for the purpose of extrapolation from the limited number of study households to national results.

What is a household?

A "household" in Living Standards Measurement Study surveys refers to "normal" households and includes the people who generally eat together; institutional and homeless households are excluded from the surveys. Thus, the total population of normal households is less than the census figure.

Measure income

HH expenditure is a proxy measure for income as it is more consistent and reliable.

Preparation: Identify location and determine income level

Determine urban and rural households adopting the definition of household used by the HH survey:

- For each (urban/rural) location, calculate income centiles.
- Determine (1) the mean monthly HH expenditure (MMHE) and (2) the number of HH members or HH size.
- Calculate the mean per capita expenditure (MPCE) as follows: MMHE/HH size.
- Rank households according to MPCE (not by MMHE).
- Create 100 quantiles (or centiles), with the centiles having relatively similar numbers of households. Note that HH size decreases with centile. Therefore, the number of persons decreases with centile and the mean HH expenditure and per capita expenditure increase with centile.
- Forecast the population of "normal" households over the modeling period using UN census projections (or using national sources) and use the projections of "Adult Population aged 20–64" to define the average number of households by location. Use projections of other age groups as "dependents" to define the average HH size by location.
- Adjust the HH size for each centile in future years so that the average (by location and year) matches the value calculated using census data.

Identify and project vehicle ownership patterns

- Among all households, for each location, and across centiles, determine vehicle ownership by type of vehicle (using the question "Does the household own one or more cars?")
- Among households owning a vehicle, determine the average number of vehicles owned by a household for a given centile for both locations (rural and urban) for each vehicle type (using the question "How many cars does the household own?")
- The analysis is conducted on car and motorcycle ownership only.

Analyze ownership

- Using the HH survey data, examine vehicle ownership patterns using a simplified model:
  - Vehicle ownership = f(Average HH expenditurei), where i is the expenditure centile.
  - Calculate parameters.
  - Use the parameters calculated from the survey for the duration of the modeling period.
  - Select the function that provides the best overall fit or use a forced saturation model that improves the fit of the curve.

The following are the three-parameter Gompertz and logistic functions used in modeling whether a household owns a vehicle:

Equation 2

$$Gompertz: \quad ownership_{i,k} = \beta_{1,k} * e^{-e\{-\beta_{2,k}*(MMHE_{i,k}-\beta_{3,k})\}}$$

Equation 3

$$Logistic: \quad ownership_{i,k} = \beta_{1,k} / \left(1 + e^{-\beta_{2,k}*(MMHE_{i,k}-\beta_{3,k})}\right)$$

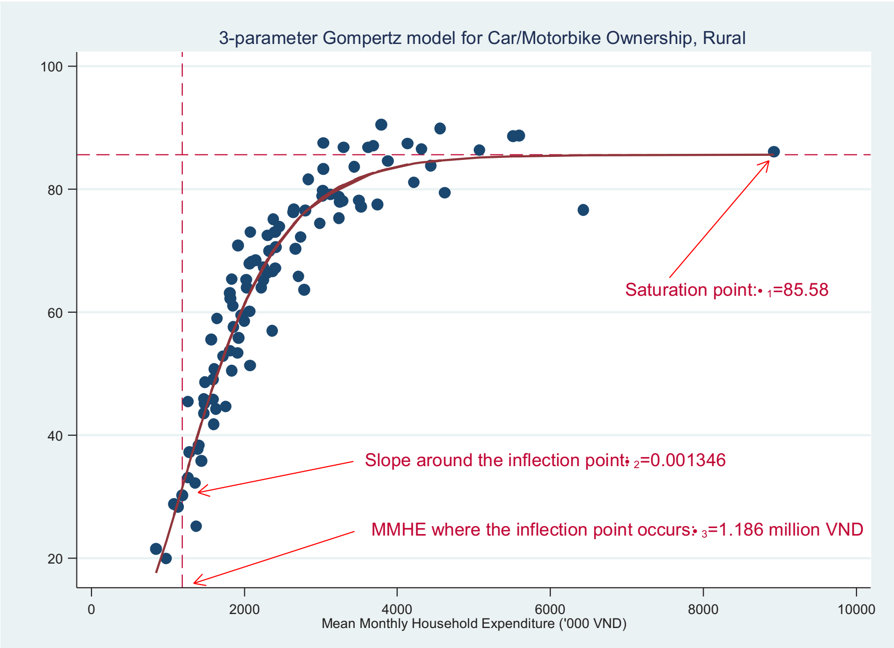
In both equations:

> *i* = The *i*th expenditure centile.
>
> *k* = Location (urban, rural).

The parameters are as follows:

> β_1 = Upper bound of the curve or the saturation level past which ownership can no longer rise.
>
> β_2 = Growth rate or how fast the curve turns toward saturation. The function will continually be increasing if > 0 and decreasing if < 0.
>
> β_3 = The inflection point, or, in this case, the average HH expenditure (MMHE) level above which electrification or ownership rises at an increasing rate.
>
> *MMHE* = Mean gross monthly expenditure of the household.

Figure 14. Three-parameter Gompertz curve for car + motorcycle ownership: Sample



Gompertz

Equation 4

$$no.\,owned_{i,k} = \beta_{0,k} + \beta_{1,k} * e^{-e-\{\beta_{2,k}*(MMHE_{i,k}-\beta_{3,k})\}}$$

Logistic

Equation 5

$$no.\,owned_{i,k} = \beta_{0,k} + \left(\beta_{1,k} / \left(1 + e^{-\beta_{2,k}*(MMHE_{i,k}-\beta_{3,k})}\right)\right)$$

In both equations:

i = The ith expenditure centile.

k = Location (urban, rural).

The parameters are as follows:

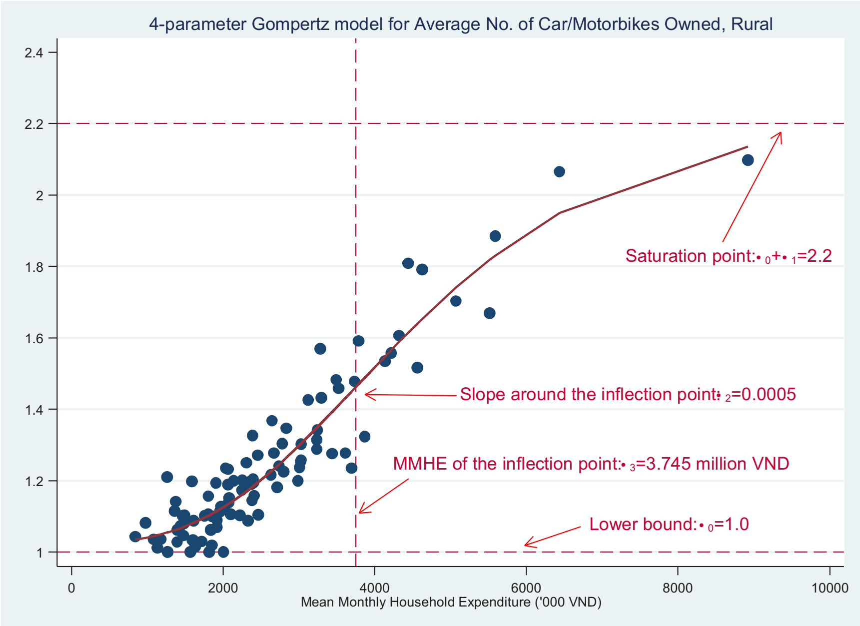
β_0 = Lower bound of the curve (which in our case is set to 1).

β_1 = The upper bound or saturation level minus the lower bound (i.e., Saturation - β_0). Hence, to obtain the saturation level, calculate $\beta_0 + \beta_1$.

β_2 = The growth rate or how fast the curve turns toward saturation.

β_3 = The inflection point or MMHE level above which electrification or ownership rises at an increasing rate.

Figure 15. Four-parameter Gompertz curve for the number of vehicles owned by a household: Sample



Gompertz functions: Forced saturation

Equation 6

$$ownership_{i,k,t} = \beta_{1,100,k} * e^{-e-\{\beta_{2,k}*(MMHE_{i,k,t}-\beta_{3,k})\}}$$

In the equation:

i = The ith expenditure centile.

k = Location (urban, rural).

t = Period.

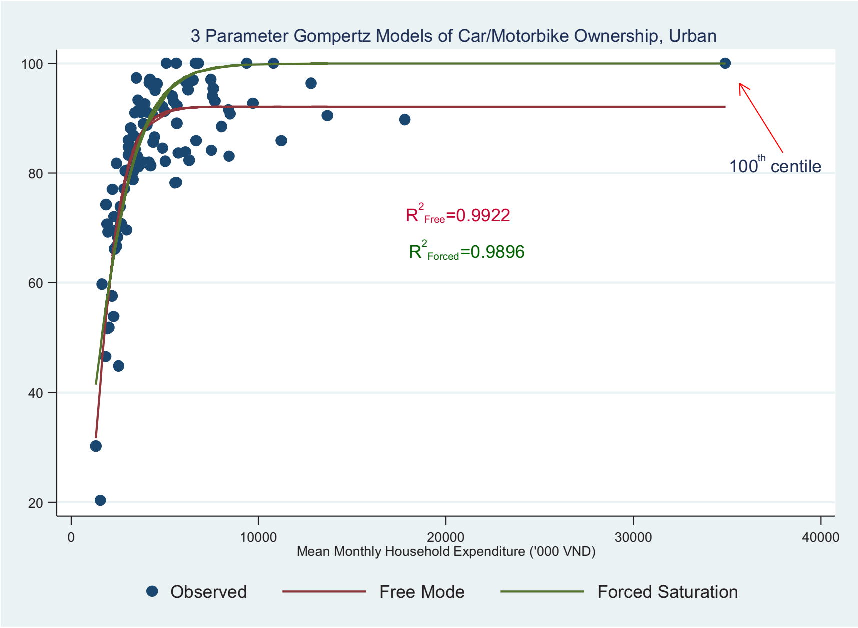
The parameters are as follows:

$\beta_{1,100}$ = Saturation level for the highest centile (centile = 100).

β_2 = How fast the curve turns toward saturation.

β_3 = The MMHE level above which electrification or ownership increases at an increasing rate.

Figure 16. Sample curve for free vs forced saturation



Note: VND

Summary of the methodology

- Prepare data by creating expenditure centiles for both urban and rural locations.
- Project MMHE over the modeling period.
- Adjust future years so that the change in HH size by location is consistent with the UN projections over the modeling period.
- Determine the relationship of vehicle ownership and HH expenditure using saturation/sigmoid/S-curves, such as Gompertz or logistic curves.
- Use the calculated parameters as inputs into the MRV model.
- Maintain the observed vehicle ownership pattern based on the saturation curve analysis during the modeling period.

The analysis described above can be performed in:[6]

- Stata,
- SPSS,
- R, or
- Excel.

To convert Stata's data files into Microsoft Excel (CSV format) using R:

- library(haven)
- yourData = read_dta("path/to/file")
- write.csv(yourData, file = "yourStataFile.csv")

To perform the analysis in R:

- Package "grofit," "easynls," or FlexParamCurve

or

- Use Microsoft Excel's Solver to fit parameters.

Baseline population of other vehicles

Add non-household-owned vehicles in figure 10, step 2; figure 11, step 1; and figure 12, step 1.

The active vehicle fleet also includes vehicles not owned by households (in use by different institutions, for commerce, and by industry, for example). This vehicular fleet has to be estimated and included in the analysis. The basis for this estimation is generally vehicle registration data. For passenger cars and motorcycles, this estimation is based on the difference between the number of registered in-use vehicles and the number of vehicles owned by households as defined above.

[6] Stata: see Stata, "The Complete Statistical Software for Data Science," https://www.stata.com/; SPSS: see IBM, "IBM SPSS Statistics," https://www.ibm.com/products/spss-statistics?utm_content=SRCWW&p1=Search&p4=43700050715561164&p5=e&gclid=Cj0KCQjw8O-VBhCpARIsACMv-VLOdLb6OknPqowr26Vto39TssJK1uAJCWdbpNgFhvInytalXQfpfI2gaAkfVEALw_wcB&gclsrc=aw.ds; R: see R Foundation, "The R Project for Statistical Computing," https://www.r-project.org/.

Note that the number of vehicles not owned by households is likely to change from year to year, although following a trajectory different from that for vehicles owned by households. The basis for estimating this change will differ between countries, depending on local knowledge. In some countries, it can be expected that the number of vehicles will not increase significantly over the coming years, while in others, estimating an increase in this fleet similar to GDP growth could be more logical.

Total base year passenger car population

Disaggregate the active fleet by vehicle category and segment (see figure 10, step 3; figure 11, step 1; and figure 12, step 1).

Vehicles differ in size, weight, use, fuel, and technology, and the active fleet has to be disaggregated to apply the corresponding emission factors to each vehicle type. The level of detail needed is shown in figure 3.

Use of vehicle registration data

If a country has reliable vehicle registration data, then this is the most reliable source for disaggregating the active fleet in the base year. There are two cases that affect how registration data can be used.

Case 1 (normal forecast)

We have the inventory of the previous year and sales for this year.

Calculate mortality for the total vehicular fleet using Winfrey applied to the previous year.

1) New inventory = Last year's inventory – Mortality + Sales.

Case 2 (normal backcast)

We have the inventory and sales in the current and previous years:

1) Calculate mortality for the total vehicular fleet using Winfrey applied to the previous year.
2) Divide by the previous year's inventory (subcategory).
3) Subtract from the current year's inventory (subcategory).
4) We arrive at sales (Current year's inventory – Previous year's inventory + Mortality) (subcategory).

Where the registration database is not sufficiently detailed or up to date, vehicle sales data can often be found for the previous 20 years. These data can be used through a mortality function to reconstrue an estimated fleet profile utilizing the logic of Equation 1. In all other cases, a survey needs to be conducted. A quick and easy way is via the "Gas station survey," which is documented separately.

Often, the registration database does not have all the required information, or some of the fields are free capture, resulting in the same data being written in multiple forms. Here, a worldwide database (e.g., https://car2db.com) can help filter the registration database and include any needed data that are absent (e.g., vehicle curb weight).

Mortality function

The preferred function to estimate vehicle mortality is the Winfrey S3 Curve,[7] modified so that during the vehicle warranty period, little or no mortality is expected (while vehicles are under warranty, most damage is repaired).

Where the average service life is defined as the period between the introduction of new assets and their active use and when 50 percent of those initial assets are still in use, the function takes the following form:

Equation 7

$$Survival = \max(0, Y_0 * (1 - ((Y - W)^\wedge 2/Aa^\wedge 2))^\wedge m))$$

Where:

Survival = Percentage of vehicles still in service.

Y_0 = 1.

Y = Years of use.

W = Warranty period in years.

Aa = Factor adjusted to give 50 percent for "Average age at retirement of A years" (years of use when only 50 percent of the original fleet is left in service).

m = 3.

Note that the average age at retirement for different vehicle types can be determined from the "Gas station survey" or using Equation 1 when vehicle population and annual sales are known over several years.

An alternative is to use the survival function shown in the IPCC (2006) guidelines V2_3_Ch3_Mobile_Combustion Box 3.2.3.

Equation 8

$$Survival = 1 - EXP(-EXP(a + b * Y))$$

Where:

Survival = Percentage of vehicles still in service after *Y* years.

a = 1.798.

b = -0.137.

Y = Years of use.

[7] See Edwin Bernard Kurtz, *Life Expectancy of Physical Property Based on Mortality Laws*, a foundational 1930 engineering textbook (Iowa State College, 1932); and Harold Andrews Cowles Jr, "Prediction of Mortality Characteristics of Industrial Property Groups," Iowa State University ProQuest Dissertations & Theses, 1957, https://www.proquest.com/docview/301919796/.

However, Equation 8 does not accommodate the difference in the in-use lives of different classes and types of vehicles.

Projected active population

Active fleet by year (in reference to figure 10, step 5; figure 12, step 6; and figure 13, step 6).

Vehicle fleet by category is then forecast for the entire the modeling period. The basis for this forecast is the growth rate calculated for privately owned cars (from the HH living standards survey analysis) and for other vehicles not owned by households.

For heavy-duty trucks and for buses (figures 12 and 11, respectively), the future population of vehicles is forecast as follows:

- Population by category and segment is determined in the base year.
- The people and goods transported in the base year are calculated from ridership or load factor data.
- The need for people and goods to be transported in future years is estimated.
- The number of vehicles needed each year is calculated based on their carrying capacity and expected load factor.

Projected changes in active population

Using the forecast total population of vehicles and the estimated annual mortality,[8] the total annual sales (of new and used vehicles entering the active fleet) are determined using Equation 1. Information on market development is used to evaluate the configuration of the vehicles included in annual sales by class of vehicles, technology type, and fuel (with a level of detail consistent with that shown in figure 3). Market demand changes, and the fact that, for example, a SUV was scrapped, does not necessarily mean that a new SUV with the same fuel and technology will be sold that year.

This differentiation is vital since it directly impacts vehicle emission factors, and it is important to identify which changes in the vehicle market are due to the policy (or intervention) being evaluated and which are exogenous.

Three basic approaches can be employed.

BAU approach

This approach is often employed as a basis for evaluating fleet changes in the counterfactual *WithoutPolicy* scenario. An identified shift in consumer preferences is extrapolated to future years along with accounting for regulatory changes, if any. For example, the passenger car segment may be seeing a shift of consumer preference toward more medium-class vehicles and fewer mini-vehicles, while stricter new car regulations demand advanced technology or higher fuel efficiency.

8 See step 3.

Marketing study approach

All vehicle manufacturers maintain sales forecasts by dress level for their respective markets. While estimates of future sales mixes of individual manufacturers are often considered proprietary information, market-level forecasts, indicating expected changes in consumer preferences and regulations, can frequently be accessed via manufacturers' (or importers') associations. These data have higher validity over the short term.

Market vision approach

This approach takes the information available on the expected longer-term market tendencies and backcasts to the current sales mix. This is useful for informing a discussion on the probable longer-term changes in consumer demand and the possible implementation of regulations affecting fuel consumption (and electrification), fuel economy, vehicle size, vehicle weight, and the future of private motorization. Constructing different scenarios can allow the model to evaluate the impact of other decisions on emissions.

An example of this would be based on the International Council on Clean Transportation's (ICCT's) report "Pathways to Decarbonization: The European Passenger Car Market in the years 2021–2035,"[9] which outlines four future scenarios, illustrated in figure 17:

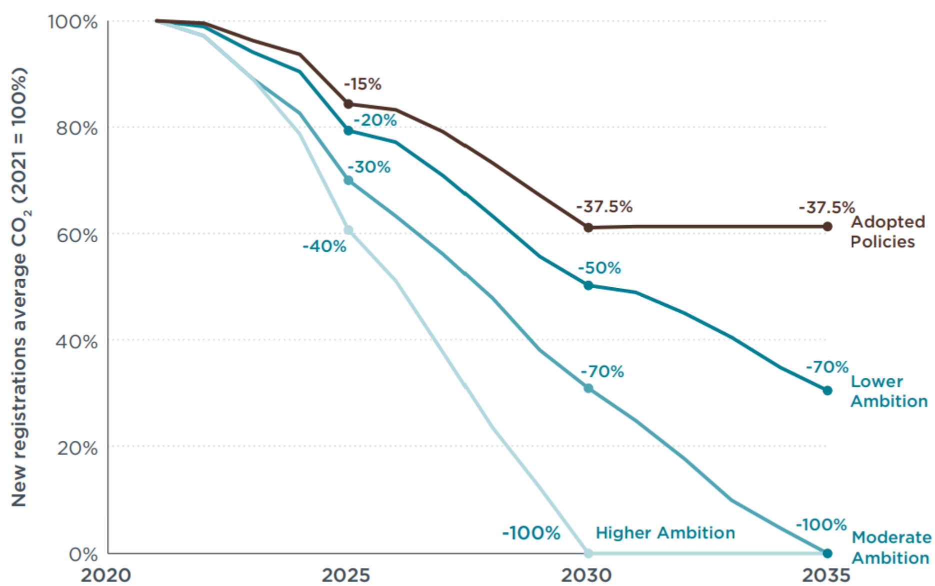
1. **Adopted Policies scenario,** where the share of both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) increases, from 7 percent in 2021 to 14 percent in 2025 and 27 percent in 2030 (table 7). Without stronger EU regulation, no further uptake of BEVs and no further technical progress is assumed beyond 2030. The Adopted Policies scenario ensures that the current EU regulatory targets of 15 percent and 37.5 percent lower CO_2 emission levels under the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), relative to a 2021 baseline, for the new passenger car fleet are reached by 2025 and 2030, respectively.
2. **Lower Ambition scenario,** where the assumption is that there is progress on the fleet average WLTP CO_2 emission target for 2025 with fleet average WLTP CO_2 emissions falling from the current 15 percent to 20 percent (table 8). From 2021 to 2025, the fleet penetration assumptions for BEVs and PHEVs remain the same as under the Adopted Policies scenario. While the share of BEVs increases to 56 percent, the share of PHEVs decreases to 13 percent. In sum, WLTP CO_2 emissions of new car fleets decrease 70 percent in 2035 relative to a 2021 baseline.
3. **Moderate Ambition scenario,** in which a complete phaseout of combustion engine vehicles by 2035 is assumed (table 9). An interim target of 30 percent lower WLTP CO_2 emissions by 2025, relative to 2021, is applied, with improvement to 70 percent lower WLTP CO_2 emissions in 2030. For 2030, the share of BEVs grows strongly to 54 percent, whereas the share of PHEVs drops to 14 percent. By 2035, all new vehicles registered are BEVs.
4. **Higher Ambition scenario,** in which the phaseout of combustion engines by 2030 is assumed, again relying entirely on BEVs. Between 2025 and 2030, the share of BEVs will rise rapidly to 100 percent, whereas all other technologies are phased out.

[9] Peter Mock and Sonsoles Díaz, "Pathways to Decarbonization: The European Passenger Car Market, 2021–2035," ICCT white paper, International Council on Clean Transportation, May 19, 2021, https://theicct.org/publication/pathways-to-decarbonization-the-european-passenger-car-market-2021-2035/#:~:text=Pathways%20to%20decarbonization%3A%20The%20European%20passenger%20car%20market%2C%202021–2035,-May%2019%2C%202021&text=As%20part%20of%20the%20roadmap,by%20the%20middle%20of%202021.

Each of these scenarios—or variants (e.g., moderate ambition with a five-year lag)—can be evaluated by the model for any client country, and their impact on GHG emissions can be determined. Note that the effect will be different from country to country, since it depends on the age and growth of the passenger car fleet, the historical technology level in the fleet, and the mix of new/used vehicles entering the in-use fleet every year.

Also, it is important to note that these forecast estimations feed into the ex ante calculation, which evaluates the possible future impact of policy decisions. They do not impact the emission reduction determination for crediting, which depends on the MRV of passenger car activity.

Figure 17. ICCT pathways to decarbonization for the EU passenger car market



Note: CO_2 = carbon dioxide; ICCT = International Council on Clean Transportation.

4. Applicability of Methodology

4.1 Determining changes in transport demand

The methodology described here is used in the *WithoutPolicy* operation only to determine changes in end-user transport demand from the policy (or other interventions) being evaluated.

The methodology seeks to construct the transport demand level in the counterfactual *WithoutPolicy* operation. In other words, it seeks to develop what would have been the level of demand had the policy package not been enacted.

The methodology accounts for user behavior and its response to investment, pricing, and regulatory policies. It emphasizes mode choice as well as technology choice. The methodology recognizes the complementarity between investment in low-emission transport infrastructure and equipment and policies that signal the social costs of transport to users, which significantly differ between environments. Transport GHG emissions depend not on the volume of transport demanded but the structure of that demand. Discrete choices on which transport mode to use, which technology to use, and on-route decisions are responsible for the eventual emissions.

Dimensions of choice

Transport emissions rely on which *transport modes* users will use. The choice is between private motorized transport, mass transit, and nonmotorized transport. Vehicle purchase locks in *technology* and fuel intensity for years, as much of the purchase price is sunk. Whether new or improved infrastructure generates additional demand or reroutes existing traffic flows, depends on how users change their *trip plans or routes*.

Not including these choice dimensions in the GHG analysis runs a high risk of a mismatch between supply and demand for modal transport services.

Determinants of behavior

Income growth, cost of mobility, and the quality of services of different modes immediately affect transport demand and emissions. They determine the changes in trends for a transport system in the absence of the investments or policy action whose consequences for GHG emissions are being evaluated. Infrastructure investment, public finance, and regulation shape transport demand indirectly through impacts on costs, time, and service availability and quality. Investments and policy action change the trend or impact baseline development in transport through these channels.

The choice of transport mode and technology and the volume of modal transport demand are strongly influenced by *income development*. For most countries, the demand for mobility increases more than proportionately with income—a trend that subsides only at very high income levels. In many cases, the demand for freight transport is proportional to GDP growth.

Monetary costs of transport services

Changes in the monetary costs of transport services determine changes in transport demand across modes. For private motorized mobility, fuel costs will dominate changes in transport expenditure. Substantial rises in fuel price diminish transport activity, leading to a shift to more fuel-efficient modes. For public transport, monetary costs are administered mainly by public authorities that prescribe ticket prices for operators. Generally, ticket prices vary slightly in the short term, much less than the prices of gasoline and diesel.

Time costs of transport services

Time costs of transport services are, in general, more important for transport demand than monetary costs. Time costs are expected to increase with income as opportunities to earn additional income during the time lost in traffic increase. With freight deliveries relying heavily on time, depending on the logistics system, the value of time in freight transport can be high, as delays create a need for more extensive inventory or lead to costly disruption of production processes. In-vehicle times are only one dimension of time costs in transport. Wait times are an additional dimension.

Quality of transport services

Finally, modal demand in transport is strongly influenced by service quality. Modal demand may depend on the quality of transport infrastructure or the comfort provided by vehicles. Often, service quality depends on the safety and security of a mode.

Estimating the impact on transport demand

There are multiple ways to estimate the price and time impacts on the demand for transport. While reducing the uncertainty of this estimate is associated with increasing effort/cost, this more significant effort may yield a more attractive emission reduction, without affecting the conservativeness of the calculation. A few approaches are discussed below.

Unadjusted transport demand

Much evidence supports a general economic theory that transport demand is negatively correlated with transport cost and time. Therefore, one would expect the level of demand (thus emissions of CO_2e) to be higher under the counterfactual *WithoutPolicy* scenario. This suggests that leaving demand unadjusted in the reference case likely establishes a conservative emission level for the measurement of the between-scenario emission difference.

Measuring the price and time effect for adjusting demand

Some of these interventions may seem relatively straightforward to model. A standard, for example, may require all new vehicles in year X to achieve a particular minimum fuel economy. The model estimates vehicle sales (by type and category) in that year, X, based on data on transport requirements and a mortality analysis for fleet replenishment. The model uses historic (or survey) data on operational use (kilometers/year) and a load factor to estimate operating costs, fuel consumption, emissions, and goods transported.

However, the analysis could become more complicated when the following considerations are made:

- The fuel economy standard may drive up the purchase cost for new vehicles. This increase in cost may modify the end-user's decision on what vehicle to purchase and when to purchase.
- The improved fuel economy may reduce operating costs and lead to an increase in operational use (kilometers/year).
- The improved fuel economy could even lead to a change in freight charges, making the fleet more competitive and changing its operating dynamics.

The example above looks at freight, but it also applies to passenger transport. The passenger travel demand curve appears to have a long tail, meaning that if travel costs to the user (monetary costs, time costs, discomfort, and costs of risks) decline sufficiently, people will tend to travel more. This will result in an increase of marginal-value travel, which offers minimal benefits to users; and if this marginal-value travel imposes external costs (e.g., GHG emissions), then its net benefits are often negative (total benefits are less than total costs). This lower-value travel tends to be highly pricing sensitive.[10]

When the alternative future low-carbon scenario includes the implementation of the above fuel economy standard (whereas the "normal" development BAU scenario does not), between-scenario differences in fleet size, operation, and fleet dynamics between could be triggered, and the overall impact on fuel economy and CO_2 emissions may be starkly different than any calculation that ignores these price-sensitive effects.

The demand adjustment (if applied) should be determined by analyzing the specific price-sensitive effect and by employing the most rigorous possible of the following approaches:

a) Time series econometric analysis
b) Panel econometric analysis
c) General equilibrium analysis
d) Adopting robust estimates from the literature

[10] Todd Litman, "Understanding Transport Demands and Elasticities; How Prices and Other Factors Affect Travel Behavior," Victoria Transport Policy Institute, December 8, 2025, https://www.vtpi.org/elasticities.pdf.

Time series econometric analysis

The dependent and explanatory variables have to be defined according to the scope of the policy (i.e., economywide, for specific sectors, or for specific consumer classes within sectors). For a universal change, time series data for total national-level transport by mode and average transport cost may be used. For specific end-user classes, an econometric analysis should be conducted individually for each user group.

A few broad principles of the analysis in this subsection are as follows:

1. The econometric specification should be chosen based on the literature and country-specific evidence. Control variables typically include per capita income, weather conditions/climate index, the prices for other travel modes, and demographic and geographical control factors.
2. Appropriate co-integration techniques and robustness tests are recommended to avoid spurious correlation and to establish credible elasticity estimates.
3. The time series should consist of historical observations for over 30 years. The data series should have the entire range of historical variation in line with the magnitude of the change in question.
4. The period of the time series should not contain significant market or political changes that could markedly skew the elasticity of demand.
5. Elasticity estimates should reflect short-run elasticity, since the methodology captures change in annual time steps.[11]

Panel econometric analysis

The panel co-integration technique may be used when a series of equivalent surveys are available across multiple years. At least four rounds of surveys spanning more than 15 years, with the difference between the ending period and the measurement year under or equal to five years, should be available.

General equilibrium analysis

The linkage between transport price and demand could also be analyzed using a computable general equilibrium model, typically constructed from a country's input–output (I–O) table or social accounting matrix. For this methodology, a static computable general equilibrium model well calibrated for the assessment year can be used to estimate the response of transport demand to price shock.

Adopting a robust estimate from the literature

Existing estimates in the literature may be adopted provided that (1) the design of the analysis and the dependent variable used for the analysis are appropriate for the type and scope of the policy under consideration and (2) the econometric method follows the requirements outlined under the section *"Time-series econometric analysis"* above and the procedure outlined therein, which involves unit-root and co-integration tests, as well as an estimate of the short-term elasticity of transport demand

[11] The use of short-run price elasticity is consistent with the principle of a conservative baseline. This is also considered pragmatic for the purpose of carbon crediting or for results-based payments against outcomes on emission reduction achieved using a manageable crediting/payment period of, say, five years, although the methodology leaves out possible long-run impacts (where there are no fixed capitals/factors).

based on an error correction model. Adopting short-term price elasticities of demand for substitution transport modes from the literature follows the same guidelines and requirements for statistical rigor.

This model and methodology, by default, adopts elasticities from the recent compilation "Understanding Transport Demands and Elasticities How Prices and Other Factors Affect Travel Behavior (June 2021)," Victoria Transport Policy Institute (Transportation Elasticities [vtpi.org], as well as other elasticities from the older seminal TRACE study and handbook (G. de Jong, *Elasticity Handbook: Elasticities for Prototypical Contexts*, TRACE project deliverable D5, EC contract RO-97-SC.2035 [Brussels: European Commission, Directorate-General for Transport, 1999]). TRACE was a comprehensive research program carried out by a consortium of European consultants and universities to understand and demonstrate the relationship between travel costs and time and the demand for car travel in the short and long terms. The program produced an easy-to-use *Elasticity Handbook* for including elasticity values for a range of "prototypical contexts," to use for assessing first-order impacts on car travel demand at different planning levels.

Elasticities

Travel demand refers to the amount and type of goods and passenger travel that would most likely be chosen in a particular situation.

Prices are the direct, perceived costs of using a good or service. Transport prices include monetary costs, travel time, discomfort, and risk. Price changes can affect trip frequency, route, mode, destination, scheduling, vehicle type, parking location, type of service selected, and location decisions. The impacts of pricing are commonly measured using elasticities, which is the percentage change in consumption (in this case, in travel activity) from every 1 percent change in price.

The preferred method for calculating transportation elasticities (symbolized as η) is the arc elasticity method and its variation, the mid-point arc elasticity method. The arc elasticity method reflects the change in consumption (Q) from every 1 percent change in price (P).

Arc elasticity

Equation 9

$$\eta = \frac{\Delta logQ}{\Delta P} = \frac{logQ_2 - logQ_1}{logP_2 - logP_1}$$

Equation 10

$$Q_2 = Q_1 \left(\frac{P_2}{P_1}\right)^{\eta}$$

Mid-point arc elasticity

Equation 11

$$\eta = \left[\frac{\Delta Q}{\frac{1}{2}(Q_1 + Q_2)}\right] \Big/ \left[\frac{\Delta P}{\frac{1}{2}(P_1 + P_2)}\right] = \frac{(Q_2 - Q_1)(P_1 + P_2)}{(P_2 - P_1)(Q_1 + Q_2)}$$

Equation 12

$$Q_2 = Q_1 \times \left[\frac{P_1(\eta - 1) - P_2(\eta + 1)}{P_2(\eta - 1) - P_1(\eta + 1)}\right]$$

Where:

η = Arc elasticity value.

P_1 = The first price point.

P_2 = The second price point.

Q_1 = The quantity point associated with the first price point (P_1).

Q_2 = The quantity point associated with the second price point (P_2).

For example, if the price of a good with -0.4 price elasticity rises 20 percent, then the resulting consumption can be calculated as 1.2^(-0.4) times the old consumption of that good, or 0.93, indicating a 7 percent reduction in consumption.

Considerations

- Elasticity analysis should use real (consumer price index–adjusted) prices instead of nominal or current prices (unadjusted for inflation). For example, if there is 10 percent inflation and nominal prices do not change during a period, then real prices will have declined 10 percent.
- The mid-point arc elasticity method should be used if one of the price values is zero (e.g., parking charge).
- **Cross-elasticities** refer to the percentage change in the consumption of a good from a change in the price of another related good.[12] For example, automobile travel is complementary to vehicle parking and a substitute for transit travel. An increase in the price of driving tends to reduce the demand for parking and increase the demand for transit travel, as a result.
- Estimation of **mode substitution factors**, such as the change in automobile trips from a change in transit trips, helps in the analysis of cross-elasticities. These factors vary depending on circumstances.

  For example, when bus ridership increases due to reduced fares, typically no more than 10–50 percent of the added trips will substitute for an automobile trip. That is, for two to ten additional

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[12] Mark Wardman, Jeremy Toner, Nils Fearnley, Stefan Flügel, and Marit Killi, "Review and Meta-Analysis of Inter-Modal Cross-Elasticity Evidence," *Transportation Research Part A: Policy and Practice* 118 (2018): 662–81, https://doi.org/10.1016/j.tra.2018.10.002.

transit trips, automobile trips reduce by one. Conversely, when a disincentive, such as parking fee or road toll, causes automobile trips to decline, there is generally a 20–60 percent shift to transit, depending on the conditions.

Some studies indicate that losses from an original endowment are valued at 2.25 times gains.[13] For example, a typical motorist could be expected to respond 2.25 times as much to a new parking fee (they pay more if they use a parking space) as a parking cash-out incentive (they receive a rebate for reducing their use of parking spaces) of the same amount.[14]

- **Multiple changes.** With various changes, travel reductions are multiplicative, not additive. For example, if three strategies are proposed for implementation, which individually provide a 5 percent, 6 percent, and 7 percent reduction in vehicle travel, the total predicted reduction is 17 percent, calculated as (1-0.05) x (1-0.06) x (1-0.07) = 17.0, not 18 percent (5 + 6 + 7 = 18).
- Elasticities vary by **trip and traveler type**. Commercial (business) travel tends to be less price sensitive than personal travel. Commuter trips tend to be less elastic than shopping or recreational trips. Higher-income travelers tend to be less sensitive to price than lower-income travelers. Weekday trips may have very different elasticities than weekend trips. Urban peak-period trips tend to be price inelastic because congestion discourages lower-value trips, leaving only higher-value automobile trips.
- **Quality and price of alternatives.** Price sensitivity tends to increase with the availability of quality, affordable alternatives. For example, highway tolls tend to be more price sensitive if there are parallel untolled roadways, and car driving is less price sensitive when transport alternatives are poor.

4.2 Evaluating changes in policy variables

The elasticities used in this model and methodology are structured into two groups:

- Vehicle ownership and
- Vehicle use (e.g., the impact of fuel price change on the demand for transport).

Any policy change can be evaluated by translating first in terms of these groups.

For example:

- The impact of increases in fuel prices can be evaluated directly. If a policy measure is to increase the fuel tax, then the effect of that tax on the average fuel price must be calculated first. If the policy is to apply a carbon tax, then the impact of this tax on the price of each fuel type needs to be calculated.
- Distance-based road pricing can also be translated to an equivalent change in fuel price and evaluated using fuel price elasticities.

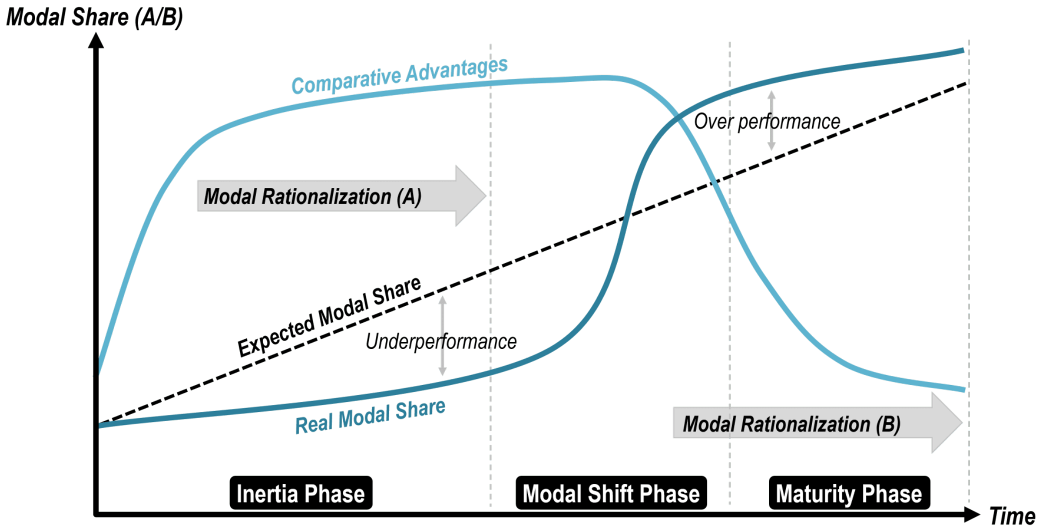
13 Richard H. Thaler, "Mental Accounting Matters," *Journal of Behavioral Decision Making* 12, no. 3 (1999): 183–206, https://onlinelibrary.wiley.com/doi/10.1002/%28SICI%291099-0771%28199909%2912%3A3%3C183%3A%3AAID-BDM318%3E3.0.CO%3B2-F.

14 Donald Shoup, "Evaluating the Effects of California's Parking Cash-Out Law: Eight Case Studies," *Transport Policy* 4, no. 4 (1997): 201–16.

- As seen in cordon-based, congestion zone charging, area-based road pricing can be evaluated using parking charge elasticities because the price to be paid is a more or less fixed amount per trip, and not a price per kilometer.
- If a policy measure is to decrease maximum speed, then the impacts on the average time to travel by car need to be calculated to be able to use the travel timetables. If the change in the speed limit impacts certain types of roads more than others, then these tables cannot give the changes in route choice, which would have to be estimated from a link-based planning model.
- If the impact on the overall travel time can be estimated, then the travel timetables can give the impact of congestion on mode choice and distribution/generation.

Many policy changes do not have an immediate, complete response from users. An example is modal shift. Modal shift happens when one mode gains a competitive advantage in a similar market. Factors that can give this advantage include costs, capacity, time, flexibility, and reliability of transport. Depending on what is being transported, the importance of each factor may be different.

Figure 18. Mechanism of modal shift



Source: Jean-Paul Rodrigue, "Principles of Modal Shift," figure in *The Geography of Transport Systems*, 5th ed. (New York: Routledge, 2020).

The modal share in the inertia phase may differ from that in the maturity phase, which is managed by applying short- and long-term elasticities (figure 18). The time needed for the market potential to reach a new equilibrium in modal shares will vary from case to case.

Some studies show ranges of elasticities. These can be usefully applied if the income effect is considered. For example, the elasticity of demand for vehicle travel against fuel price can be expected to be more inelastic for high-income groups. Some studies also show a number enclosed in parentheses. This is the most frequently found elasticity.

Source of the travel elasticities used in this model

This model currently uses, by default, elasticities from: G. de Jong, *Elasticity Handbook: Elasticities for Prototypical Contexts*, TRACE project deliverable D5, EC contract RO-97-SC.2035 (Brussels: European Commission, Directorate-General for Transport, 1999); and TRIMIS (Transport Research and Innovation Monitoring and Information System), "Costs of Private Road Travel and their Effects on Demand, Including Short and Long Term Elasticities," https://trimis.ec.europa.eu/project/costs-private-road-travel-and-their-effects-demand-including-short-and-long-term.

However, the model can be readily adapted to use values from other studies, or elasticities can be determined by the methods described above. Locally derived elasticities are preferred.

Conduct fuel efficiency and emission analysis

The steps in this section are in reference to figure 13.

This section describes how the methodology described here determines the vehicle emission factors (in grams/kilometer) that are applied to the vehicle activity measured ex post and forecast for the entire modeling period.

The methodology covers all the vehicles and technologies shown in figure 3. However, while the interest is in fuel consumption and emissions of CO_2e only, a simplifying assumption can be applied to emission standards, dividing them into two groups:

- **Lower:** All emission standards for all fuels up to and including a selected level (e.g., Euro 3/III) and
- **Higher:** All emission standards for all fuels above this selected threshold.

Vehicle operating conditions and expenditure

This section (in reference to figure 13, steps 1 and 2) describes the methodology to calculate the fuel consumption and GHG emissions from the in-use fleet of vehicles. The input data collection and analysis are described in the previous section of this paper.

Vehicle emissions and fuel consumption

Calculate vehicle emissions and fuel consumption (in reference to figure 13, step 3). The methodology is set up to use the empirical Tier 3[15] emission factors included in the COPERT 5.7.3 database.[16]

[15] The Tier 1 approach used in this methodology is based on known fuel sales only, which would have to be disaggregated to estimate emissions from passenger cars only. The Tier 2 approach is also based on fuel sales and subdivides fuel sales into each of the different technology groups according to emission control legislation. The Tier 3 approach calculates fuel consumption and emissions based on vehicle activity data.

[16] As contained in Chapter 1.A.3.b.i-iv in the EEA/EMEP Road Transport 2021 Guidebook (version 2019, updated in October 2021). See EEA (European Environment Agency), *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019* (Luxembourg: Publications Office of the European Union, 2019), https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/view.

The methodology allows calculating all exhaust emissions of carbon monoxide, oxides of nitrogen, non-methane volatile organic compounds, methane, CO_2, nitrous oxide, ammonia, oxides of sulfur, exhaust particulate matter (PM), polycyclic aromatic hydrocarbons and persistent organic pollutants, dioxins, furans, persistent organic pollutants, hexachlorobenzene, and heavy metals present in the fuel and lubricant (lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium, and zinc). Nitric oxide emissions are split into nitric oxide and nitrogen dioxide emissions.

PM is also divided into emissions of elemental and organic carbon as a function of vehicle technology. Detailed speciation for non-methane volatile organic compounds is also provided, covering homologous series, such as alkanes, alkenes, alkynes, aldehydes, ketones, and aromatics compounds. PM mass emissions in vehicle exhausts mainly fall in the PM2.5 size range. Therefore, all PM mass emission factors are assumed to correspond to PM2.5. Emission factors for particle number and surface are also provided for different particle size ranges.

The methodology does not cover non-exhaust emissions, such as fuel evaporation from vehicles, tire wear, brake wear, or road wear. However, by default, in the current model, only fuel consumption and CO_2e emissions are reported, and the other emission factor equations are not loaded, to speed up calculations.

In this Tier 3 method, exhaust emissions are calculated using a combination of firm technical data (e.g., emission factors) and vehicle activity data, as discussed in the previous section. Total vehicular exhaust emissions are calculated as the sum of hot emissions (when the engine is at its normal operating temperature) and emissions during transient thermal engine operation (termed “cold-start” emissions). It should be noted that, in this context, the word “engine” is used as shorthand for “engine and any exhaust after-treatment devices.” The distinction between emissions during the “hot” stabilized phase and the transient “warming-up” phase is necessary due to the substantial difference in vehicle emission performance during these two conditions for certain pollutants. The concentrations of certain pollutants are many times higher during the warming-up period than during hot operation, and a different methodological approach is required to estimate the additional emissions during the warming-up period.

To summarize, total emissions can be calculated using this equation:

Equation 13

$$E_{Total} = E_{hot} + E_{cold}$$

where

E_{Total} = Total emissions (in grams) of any pollutant for the spatial and temporal resolution of the application.

E_{Hot} = Emissions (in grams) during stabilized (hot) engine operation.

E_{Cold} = Emissions (in grams) during transient thermal engine operation (cold start).

Table 4 indicates for which vehicle classes and pollutants cold-start emissions have to be calculated.

Table 4. Summary of the calculation methods applied for the different vehicle classes and pollutants

Vehicle category	EC	CO_2	NO_x	CO	NMVOC	CH4	PM	N2O	NH3	SO_2	Pb	HM
Petrol passenger cars	A	C	A	A	A	A	B	A	A	C	C	C
Diesel passenger cars	A	C	A	A	A	A	A	C	C	C	C	C
LPG passenger cars	A	C	A	A	A	A		C				
2-stroke passenger cars	C	C	C	C	C	C		C	C	C	C	C
E85 passenger cars	A	C	A	A	A	A	B	A	A	C	C	C
CNG passenger cars	A	C	A	A	A	A	B	A	A	C	C	C

Key:

A Hot emissions + cold-start over emissions + evaporative losses
B Hot emissions + evaporative losses
C Hot emissions only

Note: CH_4 = methane; CNG = compressed natural gas; CO = carbon monoxide; CO_2 = carbon dioxide; EC = elemental carbon; HM = heavy metals (lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium, and zinc) ; LPG = liquefied petroleum gas; NMVOC = non-methane volatile organic compounds; N_2O = nitrous oxide; NOx = oxides of nitrogen; NH_3 = ammonia; Pb = plumbum (lead); PM = particulate matter; SO_2 = sulfur dioxide.

Vehicular emissions rely heavily on the engine operation conditions. Engine operation conditions and emission performance are distinctly different under different driving situations. In this respect, a distinction is made between driving in urban, rural, and highway environments. Different activity data and emission factors are attributed to each driving situation. Cold-start emissions are attributed mainly to urban driving (and secondarily to rural driving), as it is expected that a limited number of trips start at highway conditions. Therefore, as far as driving conditions are concerned, total emissions can be calculated using this equation:

Equation 14

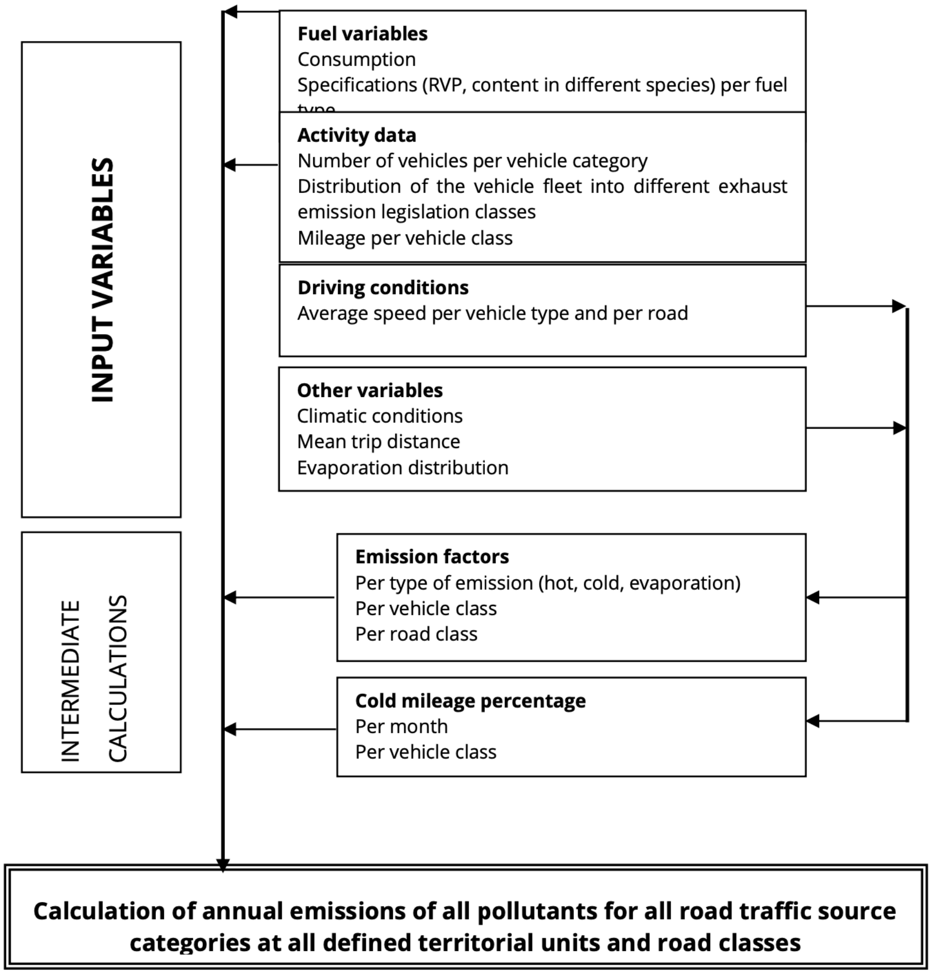
$$E_{Total} = E_{Urban} + E_{Rural} + E_{Highway}$$

Where:

E_{Urban}, E_{Rural}, and $E_{Highway}$ are the total emissions (in grams) of any pollutant for the respective driving situations.

Total emissions are calculated by combining activity data for each vehicle category with appropriate emission factors. The emission factors vary according to the input data (driving situations, climatic conditions). Figure 19 illustrates the flow chart for the calculation of total emissions.

Figure 19. Flow chart for the application of the methodology



Source: Chapter 1.A.3.b.i–iv from the EEA/EMEP Road Transport 2021 Guidebook (version 2019, updated in October 2021).
Note: RVP = reid vapor pressure.

Hot emissions

Hot exhaust emissions depend upon various factors, including the distance traveled by each vehicle, its speed (or road type), age, and weight. Hot exhaust emissions can be calculated using this equation:

Equation 15

$$E_{Hot:i,k,r} = N_k \times M_{k,r} \times e_{Hot:i,k,r}$$

Where:

$E_{Hot:i,k,r}$ = Hot exhaust emissions of pollutant *i* (in grams) produced in the period concerned by vehicles of technology k driven on roads of type r.

N_k = Number of vehicles of technology *k* in operation in the period concerned.

$M_{k,r}$ = Mileage per vehicle (kilometers per vehicle) driven on roads of type r by vehicles of technology k.

$e_{Hot:i,k,r}$ = Emission factor (in grams per kilometer) for pollutant *i*, relevant for vehicle technology k, operated on roads of type *r*.

r = Road class ("urban," "rural," and "highway").

i = The pollutants in table 4.

k = All the vehicle technologies in figure 3.

The hot exhaust emission parameters to calculate the 51,670 emission factors for all the covered vehicle types and technologies (emission factors [in grams/kilometer] or energy consumption factors [in megajoules/kilometer] or #/kilometer or #/kilowatt-hour or grams/kilowatt-hour) are found in appendix 4 to section "1.A.3.b.i-iv Road Transport," of the EMEP/EEA, *Air Pollutant Emission Inventory Guidebook 2023* (Luxembourg: Publications Office of the European Union, 2023), https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023?activeTab=22266594-97f5-4524-946f-095a50759ae7.

Cold-start emissions

Cold-start emissions are calculated as additional emissions over the emissions that would be expected if all vehicles were operated only with hot engines and catalysts warmed up. A relevant factor, corresponding to the ratio of cold-start emissions and hot exhaust emissions, is applied to the fraction of kilometers driven with a cold engine.

Cold-start emissions are introduced into the calculation as additional emissions per kilometer using this equation:

Equation 16

$$E_{Cold;i,j} = \beta_{i,k} \times N_k \times M_k \times e_{Hot;i,k} \times \left(e^{Cold} \div e^{Hot}|_{i,k} - 1\right)$$

where:

$E_{Cold;i,j}$ = Cold-start emissions of pollutant i (for the reference year), produced by vehicle technology k.

$\beta_{i,k}$ = Fraction of miles driven with a cold engine or with the catalyst operated below the light-off temperature for pollutant i and vehicle technology k.

N_k = Number of vehicles [veh] of technology k in circulation.

M_k = Total mileage per vehicle [km/veh] of technology k.

$e_{Hot;i,k}$ = Hot emission factor for pollutant i and vehicles of technology k.

$e^{Cold}/e^{Hot}|_{i,k}$ = Cold-start/hot exhaust emission quotient for pollutant i and vehicles of technology k.

The β parameter depends on the ambient temperature (for practical reasons, the average monthly temperature can be used) and the pattern of vehicle use—in particular, the average trip length. However, since information on trip length is not available in many countries for all vehicle classes, simplifications have been introduced, and a value of 12.4 km can be used, unless a firm national estimate is available.

Electricity consumption and BEVs

The COPERT database does not have emission factors for BEVs because they have no direct emissions.[17] However, the methodology and model described herein are set up to calculate and report the electricity consumption of vehicles (in kilowatt-hours). For all gasoline and diesel PHEVs, the methodology calculates energy consumption from both energy sources (e.g., gasoline and electricity used to charge the battery).

The utility factor (as shown in table 5) is applied to the COPERT emission factors, so that, for example, 37 percent of the annul mileage of a gasoline PHEV consumes electricity (from the plug-in charger) and 63 percent consumes gasoline (or electricity from gasoline). These factors are derived from the real-world use of PHEVs.[18]

For BEVs, the data set from Electric Vehicle Database, "All Electric Vehicles," https://ev-database.org/ is loaded into the model with each vehicle classified into subcategories and the average energy use (in watt-hours per kilometer) used in the calculations.

Table 5. Utility factors for different technologies and fuels

	Utility Factor
CNG Bifuel :- Gasoline	0.22
CNG Bifuel :- CNG	0.78
Diesel PHEV :- Diesel	0.63
Diesel PHEV :- Electricity	0.37
Gasoline PHEV :- Electricity	0.37
Gasoline PHEV :- Gasoline	0.63
LPG Bifuel :- Gasoline	0.22
LPG Bifuel :- LPG	0.78

Note: CNG = compressed natural gas; LPG = liquefied petroleum gas; PHEV = plug-in hybrid electric vehicle.

4.3 Carbon dioxide (CO_2) emissions

Emissions of ultimate[19] CO_2 stem from three sources:

- Combustion of fuel,
- Combustion of lubricant oil, and
- Addition of carbon-containing additives in the exhaust.

[17] Since the methodology does not include non-exhaust emissions, such as tire wear, brake wear, or road wear.

[18] Patrick Plötz, Cornelius Moll, and Yaoming Li, "Real-World Usage of Plug-in Hybrid Electric Vehicles: Fuel Consumption, Electric Driving, and CO2 Emissions," ICCT white paper, International Council on Clean Transportation, September 27, 2020, https://theicct.org/publication/real-world-usage-of-plug-in-hybrid-electric-vehicles-fuel-consumption-electric-driving-and-co2-emissions/.

[19] Ultimate in this case means that the carbon contained in the three sources is fully oxidized into CO_2.

CO_2 due to fuel combustion

If the composition of an oxygenated fuel described by the generic chemical formula $C_xH_yO_z$ is known from ultimate chemical analysis, then the mass fractions of the carbon, hydrogen, and oxygen atoms in the fuel are, respectively, *c, h,* and *o*, where *c + h + o = 1*. In this case, the hydrogen–carbon atom and oxygen–carbon atom ratios in the fuel are calculated as, respectively:

Equation 17

$$r_{H,C} = 11.916\frac{h}{c}$$

$$r_{O,C} = 0.7507\frac{o}{c}$$

With these ratios, the mass of the CO_2 emitted by vehicles of technology *k* and combusting fuel *m* can be calculated as:

Equation 18

$$E^{calc}_{CO2,k,m} = 44.011 \times \frac{FC^{calc}_{k,m}}{12011 + 1.008 r_{HC,m} + 16.000 r_{OC,m}}$$

Where:

FC^{calc} = Fuel consumption of these vehicles for the time period considered.

Table 6 gives the hydrogen–carbon atom and oxygen–carbon atom ratios for different reference blend fuels (REF) used in vehicle testing and the estimated values for non-reference fuels and blends. Oxygen in the fuel may be increased due to blending with oxygenated components and/or biofuels.

When reporting CO_2 emissions, only fossil fuel statistical consumption should be considered in the calculation. This is consistent with the IPCC 1996 and IPCC 2006 guidelines, according to which emissions associated with the use of biofuels are attributed to the land use, land-use change and forestry sector under the IPCC. Hence, for reporting, the CO_2 calculated per vehicle category should be corrected, and the calculated CO_2 emissions should be derived using Equation 18, without considering the oxygen content of the biofuel part.

Table 6. Hydrogen–carbon atom and oxygen–carbon atom ratios for different reference blend fuels (REF) used in vehicle testing and estimated values for non-reference fuels and blends

Fuel (m)	Typical Molecule	Ratio of hydrogen to carbon (rH:C)	Ratio of oxygen to carbon (rO:C)	kg CO_2 per kg of fuel	Max
Petrol	[CH1.86]x	1.86	0	3.169	2.13
Diesel	[CH1.86]x	1.86	0	3.169	1.7
Ethanol	C2H5OH	3	0.5	1.911	2.13
Methanol	CH3OH	4	1	1.373	2.13
Biodiesel	[CH]x-COOH	1.95-2.03	0.11-0.13	2.797-2.727	2.13
ETBE	C6H14O	2.33	0.167	2.584	1.7
MTBE	C5H12O	2.4	0.2	2.496	2.13
Diesel	New	1.28	0.43		2.13
Natural gas/ Biogas (REF)	CH4, market fuels also contain heavier HC	4	0	2.473	2.13
LPG (REF)	C3H8 (15%)-C4H10 (85 %), market fuels may contain different proportions	2.525	0	3.024	1.7
E5		1.92	0.026	3.063	2.13
E10 (REF)		1.98	0.053	2.694	2.13
E75		2.73	0.38	2.111	2.13
E85 (REF)		2.84	0.429	2.026	1.7
ETBE11		1.91	0.018	3.094	2.13
ETBE22		1.96	0.036	3.021	2.13
B7 (REF)		1.86	0.007	3.144	2.13
B10		1.86	0.01	3.133	1.7
B20		1.87	0.02	3.096	2.13
B30		1.88	0.03	3.059	2.13

Source: EEA, *EMEP/EEA Air Pollutant Emission Inventory Guidebook*, https://www.eea.europa.eu/emep-eea-guidebook.

Note: CO_2 = carbon dioxide; ETBE = ethyl tertiary-butyl ether; kg = kilogram; m = Fuel; REF = reference blend fuel; MTBE = methyl tertiary-butyl ether.

CO_2 resulting from lubricant oil

New and well-maintained vehicles generally need small amounts of lubricant oil, because there is an oil film developed on the inner walls of the cylinders. Prolonged engine operation generally increases lube oil consumption, and this consumption should therefore be expected to increase, on average, with vehicle age. Table 7 presents the typical oil consumption factors for different fuels and vehicle ages for passenger cars. An "old" vehicle is defined as one that is beyond its typical useful life (normally 150,000 km for a passenger car).

Table 7. Oil consumption factors for passenger cars

		kg/10,000 km		
Fuel	**Age**	**Mean**	**Min**	**Max**
Gasoline	Old	1.45	0.85	2.13
Gasoline	New	1.28	0.85	1.7
Diesel	Old	1.49	0.85	2.13
Diesel	New	1.28	0.43	2.13

Note: kg = kilogram; km = kilometer.

Emission degradation due to vehicle age

Corrections are applied to the results to accommodate the variation in emissions due to vehicle age (kilometers). The baseline emission factors correspond to a fleet of average mileage (30,000–60,000 km), and a degradation factor is therefore inherent. For petrol cars, further emission degradation—due to increased mileage—should be modeled using additional degradation factors, shown in tables 8 and 9.

Table 8. Emission degradation due to vehicle age for Euro 1 and Euro 2 petrol passenger cars and light commercial vehicles

MC = AM × MMEAN + BM	Capacity class [l]	Average mileage [km]	A M	B M Value at 0 km	B M Value at 120 000 km
Correction for V< 19 km/h (MCURBAN)					
CO – MCURBAN	0.8–1.4	29057	1.523E-05	0.557	2.39
	1.4–2.0	39837	1.148E-05	0.543	1.92
	'> 2.0	47028	9.243E-06	0.565	1.67
NOx – MCURBAN	ALL > 0.8	44931	1.598E-05	0.282	2.2
HC – MCURBAN	'≤ 1.4	29057	1.215E-05	0.647	2.1
	1.4–2.0	39837	1.232E-05	0.509	1.99
	'>2.0	4028	1.208E-05	0.432	1.88
Correction for V> 63 km/h (MCROAD)					
CO – MCROAD	0.8–1.4	29057	1.689E-05	0.509	2.54
	1.4–2.0	39837	9.607E-06	0.617	1.77
	'>2.0	47028	2.704E-06	0.873	1.2
Nox – MCROAD	'ALL > 0.8	47186	1.220E-05	0.424	1.89
HC – MCROAD	0.8–1.4	29057	6.570E-06	0.809	1.6
	1.4–2.0	39837	9.815E-06	0.609	1.79
	'>2.0	47028	6.224E-06	0.707	1.45

Source: Section 1.A.3.b.i–iv, "Road Transport," of the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2023.

Note: AM = emission performance degradation per kilometer; BM = relative emission level of brand-new vehicles; CO = carbon monoxide; HC = hydrocarbons; km = kilometer; l = liter; MC = hot emission factor correction MMEAN = mean fleet mileage [km]; Nox = Nitrogen Oxides; V = vehicle mean travelling speed in km/h.

Table 9. Emission degradation due to vehicle age for Euro 3 and Euro 4 petrol passenger cars and light commercial vehicles (and Euro 1 and Euro 2 vehicles in case of an enhanced inspection and maintenance scheme)

MC = AM × MMEAN + BM	Capacity class [l]	Average mileage [km]	A M	B M Value at 0 km	B M Value at 160 000 km
Correction for V< 19 km/h (MCURBAN)					
CO – MCURBAN	'≤1.4	32407	7.13E-06	0.769	1.91
	'>1.4	16993	2.67E-06	0.955	1.38
NOx – MCURBAN	'≤ 1.4	31313	0	1	1
	'>1.4	16993	3.99E-06	0.932	1.57
HC – MCURBAN	'≤ 1.4	31972	3.42E-06	0.891	1.44
	'>1.4	17913	0	1	1
Correction for V> 63 km/h (MCROAD)					
CO – MCROAD	'≤ 1.4	30123	1.50E-06	0.955	1.2
	'>1.4	26150	0	1	1
NOx – MCROAD	ALL	26150	0	1	1
HC – MCROAD	ALL	28042	0	1	1

Source: Section 1.A.3.b.i–iv, "Road Transport," of the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2023.

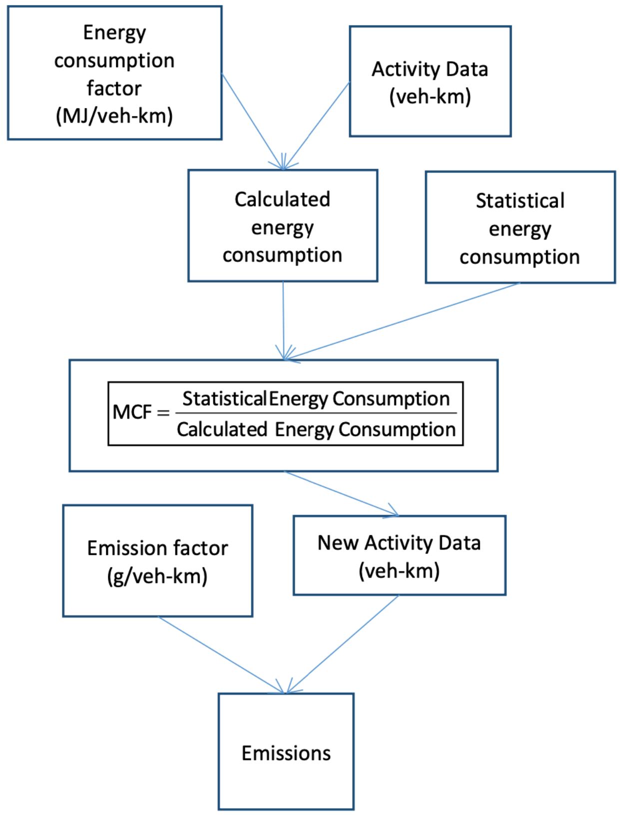
Note: AM = emission performance degradation per kilometer; BM = relative emission level of brand-new vehicles; CO = carbon monoxide; HC Hydrocarbons km = kilometer; l = liter; MC = hot emission factor correction; MMEAN = mean fleet mileage in km; Nox = nitrogen oxides; V = vehicle mean travelling speed in km/h.

Calibrate to local conditions

Calculate vehicle emissions and fuel consumption (in reference to figure 13, step 4). The methodology described here and the current model are set up to allow an energy balance calculation to match, wherever possible, the fuel consumption calculated for vehicles in the base year and reported statistical fuel sales. Often, this is difficult for diesel, because this fuel has multiple other uses (including, for example, use in off-road construction, and in agricultural machinery, generators, and pumping sets). However, this is sometimes possible for gasoline.

Where possible, in calculating vehicle fleet energy consumption, a mileage correction factor is applied to the mean activity to balance the statistical and calculated energy consumption. Figure 20 presents the adjustment algorithm.

Figure 20. Flow chart for the fuel energy balance algorithm



Source: Section 1.A.3.b.i–iv, "Road Transport," of the EEA/EMEP Road Transport 2021 Guidebook (version 2023, updated in October 2023).

Note: g = gram; MCF = Emissions Factor Correction; MJ = megajoule; veh-km = vehicle kilometer.

Determine energy consumption and emission reductions

Calculate annual vehicle emissions and fuel consumption (in reference to figure 13, steps 5–7).

This process is repeated for each year in the modeling period, using historical data in the ex post analysis and forecast data and assumptions in the ex ante analysis.

The methodology conducts this process for each of the following scenarios:

- *WithProject* measured scenario based on historical data, and
- *WithoutProject* calculated counterfactual scenario

The only difference between the two scenarios is the change in the implementation of the specific policy or intervention. Care must be taken to identify and report likely sources of leakage and ensure that all considerations in the modeling lead to conservative results.

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