ROADMAP MODEL

ICCT Roadmap model v1.6 documentation

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INTRODUCTION

The ICCT's Roadmap model is a global transportation emissions model covering all on-road vehicle activity in over 190 countries. The Roadmap model is intended to help policymakers worldwide to identify and understand trends in the transportation sector, assess emission impacts of different policy options, and frame plans to effectively reduce emissions of both greenhouse gases (GHGs) and local air pollutants. It is designed to allow transparent, customizable estimation of transportation emissions for a broad range of policy cases.

Making use of the ICCT's comprehensive tracking of worldwide transportation policies, the model provides annual estimates of historical and future emissions under currently adopted policies out to 2050. Roadmap estimates historical and projected fuel lifecycle CO_2 emissions as well as emissions of 15 local air pollutants. This version of the model includes six vehicle types and four fuel types.

Roadmap name	Vehicle category	Description
HDT	HDV	Heavy-duty trucks (GVW > 15 tonnes)
MDT	HDV	Medium-duty trucks (GVW 3.5-15 tonnes)
Bus	HDV	Urban and Intercity buses
LCV	LDV	Light commercial vehicles (GVW < 3.5 tonnes)
PC	LDV	Passenger cars
MC	MC	Two and three wheelers

Roadmap fuel	Description
Diesel	Diesel and biodiesel blends
Gasoline	Gasoline and ethanol blends
Gas	Natural gas and LPG
Elec	Zero-emission vehicles, including battery electric and hydrogen fuel cell

Many of the default model inputs are sourced from the IEA Mobility Model (MoMo)'s June 2020 version. Additional country-specific data is included for key regions where available. Using sales inputs and calibrated survival curves, Roadmap's turnover module first compiles a detailed inventory of vehicle stock. Applying per-vehicle mileage rates and energy intensities, the model next calculates detailed energy consumption estimates. These, in turn, are a key input to the emissions calculations. This document describes the inputs and methods used in each major calculation step as well as some additional optional components available to users.

SALES

Together with vehicle survival curves, annual vehicle sales are the main driver of vehicle stock within Roadmap. Default historical data on vehicle sales are sourced from the MoMo database, which provides historical sales data for 45 regions, including 31 individual countries.

Historical sales

For countries within aggregate MoMo regions, new vehicle sales are disaggregated based on each country's share of energy consumption within the region. Energy balances are derived from IEA's World Energy Balances 2019 edition, which covers road transport energy consumption by fuel type from 1971-2018. For years after 2018, the relative 2018 shares are applied. For countries within aggregate MoMo regions, country-specific vehicle sales estimates are obtained by multiplying the regional sales volumes for each of the 4 fuel types (diesel, gasoline, gas, and electric) by the equivalent regional fuel consumption shares in the World Energy Balances. Historical sales for several countries are updated using local data.

Projected sales

Sales are projected using compound annual growth rates (CAGRs) which have been calibrated based on projected vehicle activity growth rates. For EU countries, activity growth rates are derived from the [EU Reference Scenario 2016](#). For the rest of the world, growth rates are derived from MoMo's freight and passenger activity projections under the IEA's New Policies Scenario. The following equation is used to project sales for each country (C) and vehicle type (V):

$$Sales_{C,V,y2} = Sales_{C,V,y1} \times \left(1 + CAGR_{C,V,G} \right)^{y2-y1}$$

Where:
- $y1$ = The first year of the growth period
- $y2$ = The second year of the growth period
- G = The growth period $y1$ to $y2$

In all cases, the first $y1$ is the model base year (2018). For some countries and vehicles, multiple growth periods are used, in which case the calculation is performed again for the next growth period but using the original $y2$ as the new start year. For example, a region that has CAGRs defined for 2018-2030, 2030-2040, and 2040-2050 will result in projected sales for 2030, 2040, and 2050. Finally, intermediate years are linearly interpolated.

Used vehicle imports

Roadmap includes default data quantifying total imports of used vehicles and estimates their characteristics based on country-specific import policies. The top vehicle-importing regions are Africa (excluding South Africa), the Middle East (excluding Israel), Latin America (excluding Argentina, Brazil, and Chile), Japan, Russia, and New Zealand. It should be noted, however, that data on used vehicle flows is sparse and often lacks detail on vehicle types and final destinations. For example, a large quantity of used vehicles imported to the United Arab Emirates are quickly re-exported to African countries (UNEP, 2020) and as a result may be reported as imports to both the United Arab Emirates and the final destination. Roadmap accounts for used vehicle exports by adjusting vehicle survival rates.

To support flexibility in modeling used vehicle imports, Roadmap treats used sales as an annual share of total sales. (Alternatively, users can specify the share of used sales compared to new sales, as is done for intra-EU trade as discussed below.) Users can therefore provide the model with alternate data for new sales, used sales, or total sales individually without needing to adjust the other assumptions.

As per Ecologic (Ecologic, 2020) Intra-EU trade is largely from Western European countries such as Germany, France, Netherlands etc. to Eastern European countries such as Poland, Romania, and Bulgaria. EU countries are also allowed to export vehicles to select non-EU neighbors such as Serbia, Turkey, and Albania. Passenger cars are the most imported used vehicle. Most countries will consider the amount of air pollution that is generated by an imported vehicle when calculating their registration tax, and some countries such as Finland, Hungary, and Serbia outright ban the import of vehicles that do not adhere to certain EU pollution standards (generally at least Euro 3 for passenger vehicles, and Euro 5 for commercial vehicles). The Ecologic report also estimates the volume of used vehicles imported by specific countries in 2017. These volumes are used in conjunction with the new vehicle sales data from the model to obtain a used/new sales ratio for each country and vehicle type, which by default is assumed to be constant going into the future.

The ages and emission control technologies of used vehicle imports are determined one of several ways:

1. Based on the maximum age limit set by some vehicle-importing countries
2. Based on the minimum Euro standard set by some vehicle-importing countries
3. Based on country-specific assumptions for the average age of used vehicle imports
4. Based on default ages applied to countries with no specific input data

See the emission standards section for more details on determining the age of used vehicle imports.

Because vehicle imports are highly variable year to year, by default the model assumes that the future ratio of used imports to new vehicle sales is an average of the 5 most recent years of data. This share is assumed to remain constant for all projected years; however users may provide alternate shares to replace the default assumptions.

STOCK TURNOVER

Roadmap keeps track of the age distribution of the fleet at every timestep based on new vehicle sales, the import age of used vehicles, and region- and vehicle-specific retirement rates. There are two methods used to estimate stock turnover: one is based on the fraction of vehicles surviving from the original sales year, and the other is based on the fraction of vehicles surviving from one year to the next.

From-age-zero turnover

From-age-zero survival curves represent the fraction of vehicles surviving from the original sales year. These survival curves are modeled using Weibull distributions (see Hao et al. (2011) for more details).

These survival curves are defined as:

$$e^{-(x/\lambda)^k}$$

Where:
- x = Age of vehicle
- λ = Steepness parameter
- k = Shape parameter = 5

Example from-age-zero survival curves
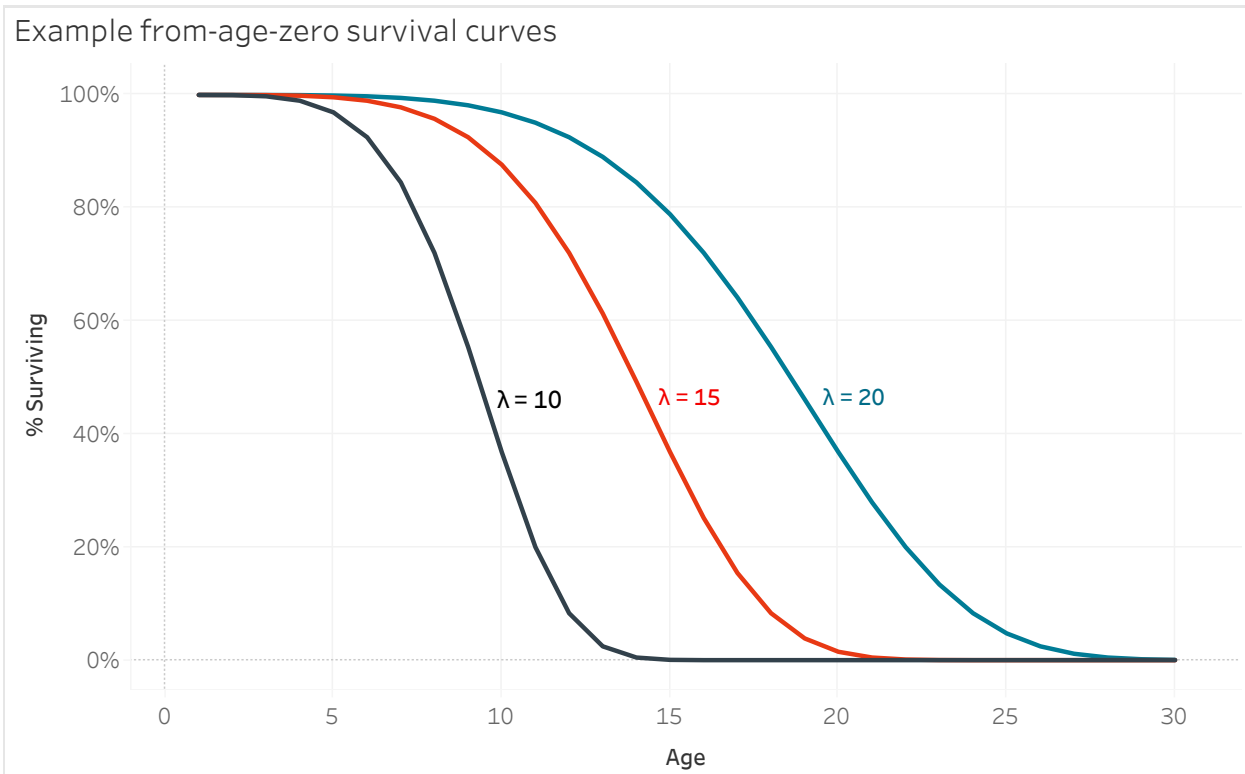
The steepness parameter is calibrated using historical stock and sales inventories. For most regions, the default from-age-zero survival curves are calibrated using stock and sales data from the MoMo database; however, some regions use more-detailed national fleet data for recent years. For each country (C) and vehicle type (V), the vehicle stock in a calendar year (CY) of a given model year (MY) is calculated:

$$Stock_{CY,MY} = Sales_{MY} \times Survival_{C,V}(CY - MY)$$

From-age-zero survival curves are applied by default to all countries for new sales as well as used vehicle imports. For used vehicles, these survival curves apply starting from when the vehicle enters the country.

Year-over-year turnover

The alternate method for estimating fleet turnover uses year-over-year survival curves. These curves represent the fraction of vehicles surviving from one year to the next. To be used effectively, a comprehensive inventory of the fleet broken down by age should be given for the base year. Unlike the from-age-zero survival curve method, used vehicles are actually treated as the age they are and not considered "new" when they enter a fleet. In this case, for each country (C) and vehicle type (V), the vehicle stock in a calendar year (CY) of a given model year (MY) is calculated:

$$Stock_{CY,MY} = Stock_{CY-1,MY} \times Survival_{C,V}(CY - MY)$$

In the case of age zero vehicles (CY = MY), sales are used instead of the previous year's stock:

$$Stock_{CY,MY} = Sales_{MY} \times Survival_{C,V}(0)$$

The year-over-year curves are applied by default to EU countries for new sales as well as used vehicle imports. This method is applied in order to accommodate detailed inputs on the starting age distribution of the vehicle stock and to model intra-EU vehicle trade.

MILEAGE

Total vehicle-kilometers traveled (VKT) is calculated by multiplying the number of vehicles in the stock by the average annual mileage, based on the vehicle type and country. Historical per-vehicle mileages are input and calibrated to align model estimates of energy consumption with historical energy balances. Unless otherwise specified, annual mileages are assumed to remain constant in future years.

Mileage degradation

Optionally, an age-based mileage adjustment can be made which applies mileage degradation curves to the fleet. This does not significantly alter total VKT, but it shifts mileage to newer vehicles.

Scrappage policies

Roadmap can also model the impacts of policies that are designed to shift activity from older, typically more polluting, vehicles to newer vehicles. Examples of such policies include scrappage and/or retrofit programs and low-emission zones. While these policies are likely to have effects on vehicle stock, these policies are currently only modeled as shifts in VKT among vehicle technologies as opposed to affecting the total level of VKT or vehicle stock. In other words, any scrappage of older vehicles (that would have traveled a certain amount of VKT) is treated as an equivalent increase in VKT by newer vehicles.

This module takes as an input the percent of VKT for each specified vehicle population (based on any of age, standard, vehicle type, fuel type) that should be reassigned to newer vehicles. Users can also specify the fuel type and model year of the vehicles that receive the shifted activity.

VEHICLE EFFICIENCY

Roadmap's default data on the energy intensities of new vehicles are derived from a combination of country-specific data sources, ICCT analyses, and historical data from the MoMo database. Vehicle- and powertrain-specific energy intensities by model year are sales-weighted and adjusted to reflect differences between on-road performance and test cycle values. In countries that are not covered individually by available data sources or analysis, default energy intensities are based on the matching aggregate region in the MoMo database.

Because many regions do not yet have substantial volumes of EV sales covering all vehicle types, the energy intensity of EVs is determined separately. By default, EV energy intensity inputs are defined as a ratio of ICE energy intensity (e.g., 0.3). These ratios are based on gasoline vehicles of the same type for MC and PC and on diesel vehicles of the same type for all other vehicle types. Users can adjust these energy intensity ratios for any combination of countries, vehicle types, and model years.

Projected new vehicle energy intensities are calculated based on user-specified inputs. By default, these inputs are specified as annualized rates of efficiency improvement by vehicle type for 16 world regions (defined in the model as RoadmapRegion); however, the user can supply detailed inputs for any combination of countries, vehicle types, fuel types, and calendar years. These inputs are intended to reflect changes in real-world fuel consumption (after applying on-road adjustment / CO_2 gap).

EMISSIONS

Emissions standards

On-road emissions are heavily dependent on the emissions control technologies of the vehicle fleet. The Roadmap model contains a frequently updated database of emission control regulations for at least 75 countries and the EU. Roadmap assumes that from the year a regulation takes effect onward, all new vehicles are sold with the required emission control technologies. (For more on how Roadmap accounts for tampered/degraded controls, see High emitters below.) Emission standards are classified based on their closest equivalents within the Euro, US, or China emission standard categories.

The emission standards of imported vehicles are more difficult to determine. Many countries have policies that restrict old or dirty vehicles. The three cases included in Roadmap are:

1. A complete ban of used vehicle imports

2. Restrictions based on vehicle's age
3. Restrictions based on vehicle's standard

In case 1, the country cannot import used vehicles at all, so all vehicles follow the same emission standard timeline. In case 2, it is conservatively assumed that all imported vehicles are the maximum age allowed. The import year and import age are used to calculate the model year of the entering vehicles. The vehicle's model year is matched to the emission standard timeline of the *exporting* country, which is used as the standard for all vehicle imports that year. If no export country is specified, it is assumed that vehicles are sourced from a region following the EU timeline. If multiple export countries are given, the timeline is taken from the country with the greatest share of the exports.

In the third case the emission standard is restricted to the standard given by the country's policies. This case can also be used to directly input the emission control levels assumed for imported used vehicles. Using the reverse process used in case 2, this standard is used to estimate the age of the entering vehicle. Similarly, it is conservatively assumed that all imported vehicles are the maximum age that still comply with the control standard.

In all cases, Roadmap assumes the emissions performance of used vehicle imports is equivalent to or worse than new vehicles.

Emission factors

Tailpipe emission factors are sourced from a combination of emission factor models, ICCT analyses, and other technical studies. Emission factors for vehicles certified to European-equivalent standards are based primarily on the European Environment Agency's European Monitoring and Evaluation Programme (EMEP), the Handbook Emission Factors for Road Transport (HBEFA), and ICCT adjustments. Emission factors for vehicles certified to US- and China-equivalent standards are sourced from EPA's MOtor Vehicle Emission Simulator (MOVES) with ICCT adjustments and ICCT's China model, respectively. Currently the Roadmap model does not estimate non-exhaust emissions such as brake and tire wear.

As both HBEFA and EMEP provide emission factors for a larger variety of vehicle types and weight classes than Roadmap, we first aggregate the emission factors to the Roadmap categories. The emission factors for 19 countries are aggregated with local, up-to-date stock inventories. HBEFA emission factors are used for buses and include a weighting of urban vs. intercity buses in addition to vehicle weight class. Emission factors for other vehicle types are sourced from EMEP, however the additional detail by weight class is only given for trucks. By default, other countries that follow the EU regulatory pathway use emission factors based on the average

fleet composition from the EU countries with available data; however, users can supply any set of country-specific emission factors.

For the United States and Canada, vehicle emission factors are based on EPA's MOVES 2014a model. MOVES estimates diesel, gasoline, and natural gas emission factors for vehicles following the US standards. Newer heavy-duty vehicles in Mexico are assumed to be partially sourced from the USA and thus are assigned a weighted emission factor based on US and EU standards. China-specific emission factors are sourced from the ICCT's China model, which incorporates data from the Vehicle Emission Control Center and Tsinghua University.

Further adjustments were made to the PM and NOx emission factors certified to US and EU regulatory pathways based on real-world performance data, including remote sensing measurements, recent PEMS testing, and planned updates to MOVES. Roadmap also supports additional speciation of $PM_{2.5}$ for all regions into components BC, OC, non-carbon organic matter, NO_3, NH_4, elemental metals, and unspeciated PM, based on Table C-1 and Table C-3 of MOVES2014.

High emitters

Emission factors derived from the models above are based on typical operation of emission control technologies averaged over all driving conditions. In addition, Roadmap accounts for high emitters—vehicles whose emissions control systems are malfunctioning as a result of tampering, poor maintenance, or failure. These vehicles produce emissions that are substantially higher than typical vehicle operations. By default, high emitter effects are currently only considered for PM and NO_X emissions from diesel vehicles.

Roadmap includes estimates of the shares of high-emitting vehicles for eight countries, the EU, and the rest of the world, ranging from 0% for some vehicle types and regions up to 20% for others. These shares are based on region-specific estimates and general compliance and enforcement levels for PM and NO_X. An emissions multiplier is used for each control level to determine the emission factors of high-emitting vehicles relative to a typically functioning vehicle of the same type.

As tampering, malfunction, and poor maintenance affect emissions based on the vehicle's age, we follow EMFAC and MOVES's approach to estimate high emitters' emission deterioration. As shown in the figure below, this approach models a linear increase in emission rates from the end of the warranty period (the first dashed line) up to the defined useful life age (the second dashed line). Once the useful life age is reached, we assume a constant emission rate equal to the product of the emissions multiplier and the baseline emission factor. Roadmap derives both the warranty age and the useful life age from region-specific regulations and vehicle activity.

Mileage was converted to age based on region-specific data that show how quickly different types of vehicles accumulate miles. We use TRACCS data for the EU and activity data from VECC for China, which is also consistent with the estimate from Huo et al. ([Huo et al., 2012](#)). We use the same ages for the US as in MOVES. In addition, we distinguish warranty and useful life ages by control level. For example, China only starts to have warranty requirements in China VI, and more recent standards, for example, China VI, Euro VI and US2004+, require a longer useful life than earlier standards.
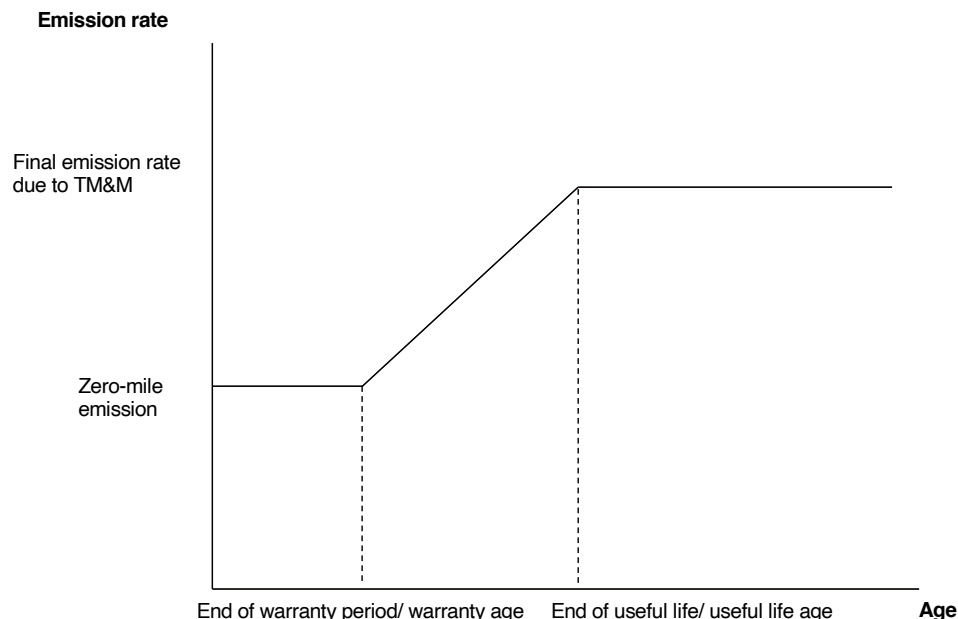
Qualitative depiction of the implementation of tampering, mal-maintenance, and malfunction (TM&M) age effects. Adapted from MOVES2014 technical report.

Sulfur effects

Fuel sulfur effects on sulfate (SO_4) and sulfur dioxide (SO_2) running emissions apply [MOVES2014a methods](#) (equations 9-1 and 9-3).

$$SO_2(g) = FC(g) \times [S](ppm) \times \frac{MW_{SO_2}}{MW_S} \times fSO_2 \times \left(\frac{10^6}{ppm}\right)$$

Where:
- $FC(g)$ = fuel consumption (grams)
- $[S](ppm)$ = fuel-sulfur level (ppm)
- $\frac{MW_{SO_2}}{MW_S}$ = the ratio of molecular weight of sulfur dioxide to sulfur = 2.0
- fSO_2 = Fraction of fuel sulfur that is converted to gaseous SO_2 emissions (1 - fraction converted to SO_4).

This equation simplifies to:

$$SO_2(g) = FC(g) \times SO_2\ EF\ (g/ppm) \times S(ppm)$$

where SO_2EF is the emission factor specific to HDVs and LDVs by emission control technology.

SO_4 emissions are calculated:

$$SO4_x = NonECPMB \times S_B \times \left[1 + F_B \times \left(\frac{x}{x_B} - 1 \right) \right]$$

Where:
- $NonECPMB$ = the reference non-elemental carbon $PM_{2.5}$ emission rate
- S_B = the sulfate reference fraction
- x = the user-supplied fuel sulfur level
- x_B = the reference fuel sulfur level
- F_B = the percentage of sulfate originating from the fuel sulfur in the reference case
- $SO4_x$ = sulfate emissions at the user-supplied fuel sulfur level

The S_B, F_B, and x_B, parameters vary by vehicle type, model year group, and emission process.

Biodiesel effects

Roadmap can also optionally model the impact of biodiesel blends on NO_X and PM emissions. Emission multipliers developed by the ICCT take into account country-specific differences in feedstock, fuel sulfur level, and biodiesel blend level. Currently, biodiesel effects are only available for the United States, Indonesia, and Brazil.

CO_2 emissions

Unlike other pollutants which depend on vehicle emission control technologies, CO_2 emissions are calculated based on energy consumption and fuel carbon intensity. By default, the model calculates tank-to-wheel (TTW), well-to-tank (WTT), and well-to-wheel (WTW) CO_2 emissions. Default fuel carbon intensities are specified in grams of CO_2 emitted per megajoule of energy consumption:

Fuel	Unit	TTW CO_2	WTT CO_2	WTW CO_2
Gasoline	g/MJ	72.44	21	93.44
Diesel	g/MJ	74.86	20	94.86
Gas	g/MJ	62.68	7	69.68

Default inputs for the carbon intensity of electricity consumption are sourced from the IEA's World Energy Outlook (WEO) 2019 scenarios. Electricity grid average carbon intensities are specified for the 32 World Energy Model (WEM) regions in the years 2018, 2020, 2025, 2030, 2035, and 2040. Since WEO 2019 projects electricity carbon intensity only out to 2040, the default Roadmap inputs extrapolate the annual improvements in electricity carbon intensity from the period 2035-2040 until 2050 but caps the maximum reduction at 95% from 2018 levels. Users can either choose one of the two WEO 2019 scenarios—Stated Policies Scenario (STEPS) or Sustainable Development Scenario (SDS)—or provide their own inputs for any combination of countries and years.

POLICIES AND SCENARIOS

The Roadmap model is designed to explore the implications of national and regional policies. Users can provide inputs defining alternate scenario pathways or updating baseline assumptions.

Scenario inputs

Scenarios can define the following inputs:

Input	Description
Sales shares	Share of vehicle sales by powertrain type
Sales	Historical country-specific vehicle sales
Energy intensity	New vehicle energy intensity (absolute or relative to the baseline)
Fuel sulfur	Diesel and gasoline sulfur content by year
New vehicle standards	Emission standard timeline for new vehicles
Import restrictions	Age or standard-based restrictions on used vehicle imports
Fleet renewal policies	Annual activity shifts by vehicle and technology which could represent low emission zones, retrofits, or scrappage policies
Emission factors	Emission factors by country, vehicle, fuel, and control technology
High emitter parameters	High emitter shares, emissions multipliers, warranty length and useful life ages

Electricity carbon intensity	Electricity grid carbon intensity by year
Alternate fleet estimate	Alternate fleet dataset including sales, stock, and activity

Integration with other models

The scenario input for alternative fleet estimates allows users to integrate region-specific fleet projections with the Roadmap model. This can be useful for projecting emissions in cases where detailed vehicle fleet projections are already available. For example, an analysis focused on the USA could make use of fleet activity and fuel efficiency projections from EPA's Motor Vehicle Emission Simulator (MOVES) model. Data from an external model such as MOVES must first be mapped to Roadmap's vehicle and fuel categories, however, and is required to include estimates of stock, sales, activity, and energy intensity by model year and calendar year. Provided this level of detail, Roadmap can estimate detailed emissions, accounting for emission standards, high emitters, sulfur effects, and biodiesel effects as usual.

Subregional policies

Roadmap's default data inputs represent best estimates of each country's total fleet of on-road vehicles. For some analyses, however, it can be useful to model the effects of policies implemented at a more granular level, such as states or provinces within a country. Roadmap can run analyses for any number of arbitrary subregions by using national fleet data, if appropriate downscaling factors are provided. When running in the subregion mode, all model results including vehicle stock, sales, activity, energy consumption, and emissions are output for each subregion.

In order to toggle the subregion mode, users must provide a mapping file indicating in which country/region (denoted by ISO alpha-3 code in the model) the subregion is located. Additionally, sales for all vehicle types must be provided for each subregion, either as a share of the regional total or as absolute numbers of vehicles. If data are only available for a subset of years, the model will extrapolate the subregional sales shares to cover all model years. Note that the specified subregions do not have to cover the entire country/region, in which case a subregion labeled "Other" is created to represent the missing share. Further downscaling factors are only required if running an energy calibration (which needs on-road energy consumption for each subregion) or certain kind of stock turnover analysis. In the latter case, as mentioned in the Stock Turnover section, stock distribution by age is required if modeling a subregion within a country/region that uses year-over-year survival curves.

Subregional stock totals are also required if calibrating subregion-specific survival curves.

Besides the inputs used as downscaling factors, all other subregion inputs such as annual vehicle mileage, energy intensity, and emission factors are inferred from the larger region by default. The user may optionally provide subregional detail for any of the scenario input files that are supported by the model, except for total vehicle sales. As a subregion's total vehicle sales or share of national sales are used to define its baseline vehicle fleet as a subset of the national fleet, varying subregion sales as a scenario input is not supported.