ROADMAP MODEL

ICCT Roadmap model v1.5 documentation

1/1/2021

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Table of Contents

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 understanding of worldwide transportation policies, the model provides annual estimates of both current emissions and future emissions under currently adopted policies out to 2050. Roadmap estimates historical and projected fuel lifecycle CO_2 emissions as well as 15 local air pollutants. 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
Gasoline	Gasoline and ethanol blends
Gas	Natural gas and LPG
Elec	Zero-emission vehicles, including battery electric and hydrogen fuel cell

Many of the key 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 from MoMo and calibrated survival curves, Roadmap's turnover module first compiles a detailed inventory of vehicle stock. Applying per-vehicle mileage rates and energy intensities from MoMo, the model next calculates detailed energy consumption estimates. These, in turn, are the key input to the final 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

Annual vehicle sales are the main driver of vehicle stock within Roadmap. MoMo 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 2017 edition, which covers road transport energy consumption by fuel type from 1971-2015. For years after 2015, the relative 2015 shares are applied. Based on the relative amounts of fuel consumption in the World Energy Balances, Roadmap disaggregates vehicle sales into 4 technology types: diesel, gasoline, natural gas, and electric. 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 to projected vehicle activity growth rates. For EU regions, activity growth rates are derived from the EU Reference Scenario 2016. For the rest of the world, MoMo growth rates are used. 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 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 a certain country (2017 being the year of estimate), and this volume is 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 is assumed to be constant going into the future.

Vehicle age is necessary for year-over-year turnover calculations and estimating the control technologies and is 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 the average age specified in the used vehicle imports data set
4. Based on default ages for countries with no specific input data

See the emission standards section below for more details on determining vehicle age.

Because vehicle imports are highly variable year to year, the model assumes that future shares of new versus used 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 for EU countries and another for all other regions.

From-age-zero

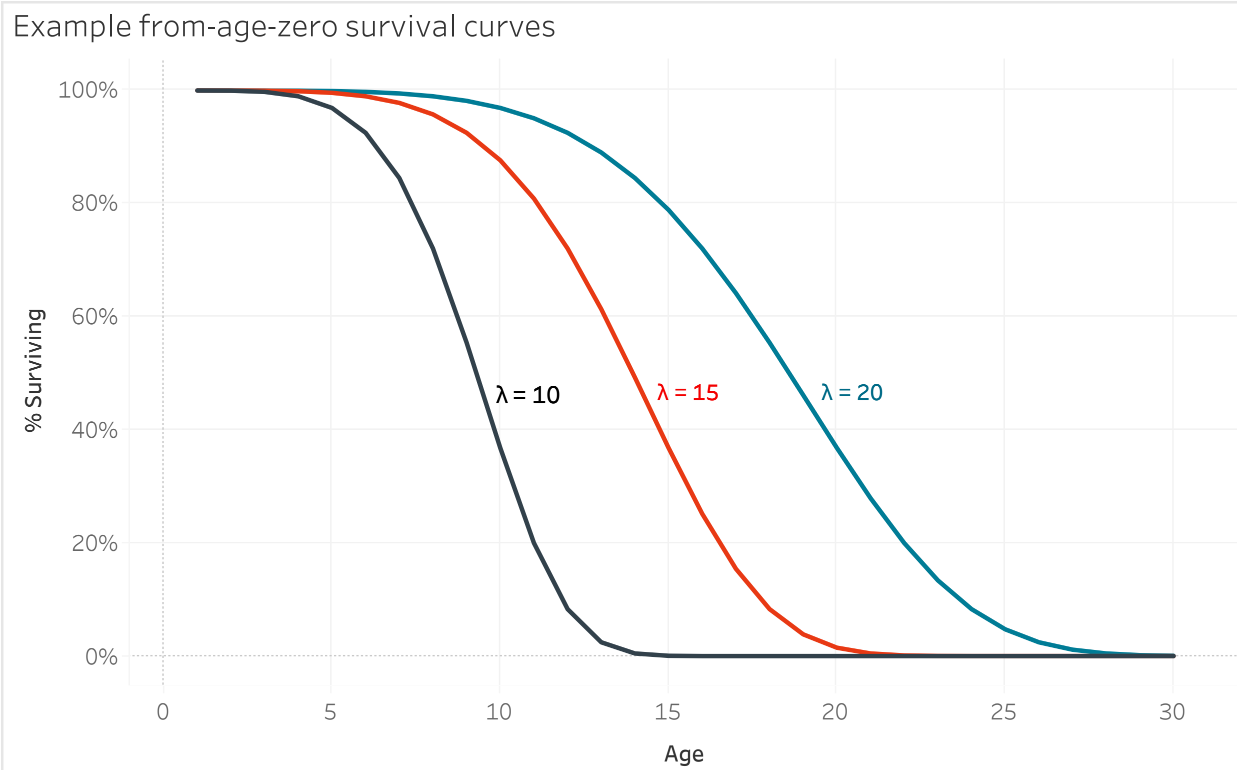
From-age-zero survival curves represent the fraction of vehicles surviving from the original sales year. For used vehicles this means that the survival rates are not set based on age, but rather how long the vehicle has been in the country. These survival curves are modeled using Weibull distributions (see Hao et al. (2011) for more details).

Survival curves are defined:

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

Where:

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



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

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

EU countries and 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:

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

MILEAGE

Total vehicle-kilometers traveled (VKT) is calculated by multiplying the number of vehicles in the stock by the average annual mileage, based on vehicle type and country. Per-vehicle mileage rates 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 will not significantly change total VKT but shifts mileage to newer vehicles.

Scrappage policies

Roadmap can also model policies that are designed to limit the number of certain types of vehicles (typically older, more polluting, vehicles) on the road. While these policies may have an effect on vehicle stock, the target of these policies is vehicle activity and so are only modeled as affecting VKT. Typically, these policies are either scrappage policies and low-emission zones.

The key premise is that these policies are modeled as changes in the distribution of VKT across the fleet as opposed to changes in stock. Therefore, any scrappage of older vehicles (that would have traveled a certain amount of VKT) results in an equivalent increase in VKT of newer vehicles. This module takes as input a percent of VKT for a vehicle population (based on any of age, range, 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 includes vehicle- and powertrain-specific fuel economy for historical model years. The fuel economy database contains vehicle and fuel types that are more detailed than Roadmap’s vehicle and fuel categories but less detailed than Roadmap’s individual countries. Average fuel economy is first determined by calculating the sales-weighted average for new vehicles, using sales volumes from the same database. Individual countries within each aggregate region are assigned the same energy intensity values.

Because many regions have little or no EV sales for each vehicle type, the energy intensity of EVs is determined separately. Instead of trying to extrapolate from the incomplete fuel economy data, we assume EV energy intensity is just a fixed fraction of ICE energy intensity. The fraction is based on gasoline vehicles of the same type for MC and PC, and diesel vehicles of the same type for all others.

Vehicle	ICE fuel	EV efficiency fraction
MC	Gasoline	0.22
PC	Gasoline	0.26
LCV	Diesel	0.26
MDT	Diesel	0.24
HDT	Diesel	0.23
Bus	Diesel	0.23

Fuel economy is projected by applying annualized changes in energy intensity for each vehicle type out to 2030 for 16 world regions (defined in the model as RoadmapRegion). Annual rates of efficiency improvements are the same for all ICE vehicles. These inputs reflect annualized reductions in real-world fuel consumption (after applying on-road adjustment / CO2 gap). No efficiency improvements are assumed from 2030 to 2050.

The ICCT additionally estimates annual energy intensity improvements (2020 to 2030) for China and Japan based on currently adopted policies.

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 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 harder to determine. Many countries have policies that restrict old or dirty vehicles. The three cases Roadmap models 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. 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 primarily sourced from the European Environment Agency's European Monitoring and Evaluation Programme (EMEP) and the Handbook Emission Factors for Road Transport (HBEFA) with the exception of the USA and China. Electric and other zero-emission vehicles are assumed to not emit any air pollutants. Currently the Roadmap model does not estimate non-exhaust emissions such as brake and tire wear.

HBEFA models emission factors for a wide variety of traffic situations, weight classes, and vehicle types with Euro control levels. Roadmap uses HBEFA emission factors for buses, averaging the emission factors for urban and intercity buses for 19 countries where up-to-date stock inventories are available. Other countries use an average of all buses and traffic situations.

Emission factors for diesel vehicles and gasoline LCVs are sourced from EMEP. Several vehicle segments are disaggregated by weight class, which are similarly to HBEFA aggregated using stock inventories for 19 countries.

The USA and Canada follow emission control regulations developed by the EPA. The EPA's MOtor Vehicle Emission Simulator (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 of US 2010 and Euro VI values. China-specific emission factors are taken from the ICCT's China model.

High emitters

Emission factors derived from the models above are based on emission control technologies performing under various 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 substantially higher than regulatory limits. High emitter effects are limited to PM and NO_X emissions.

Roadmap includes estimates of the shares of high-emitting vehicles for eight countries, the EU, and the rest of the world, based on region-specific estimates and general compliance and enforcement level for PM and NO_X. An emissions multiplier is used for each control level to determine the emission factors of the broken technologies. The methods used follow EMFAC and MOVES' approach to estimate emission deterioration from the end of the warranty period to the end of useful life.

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 $SO_2\,EF$ 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.

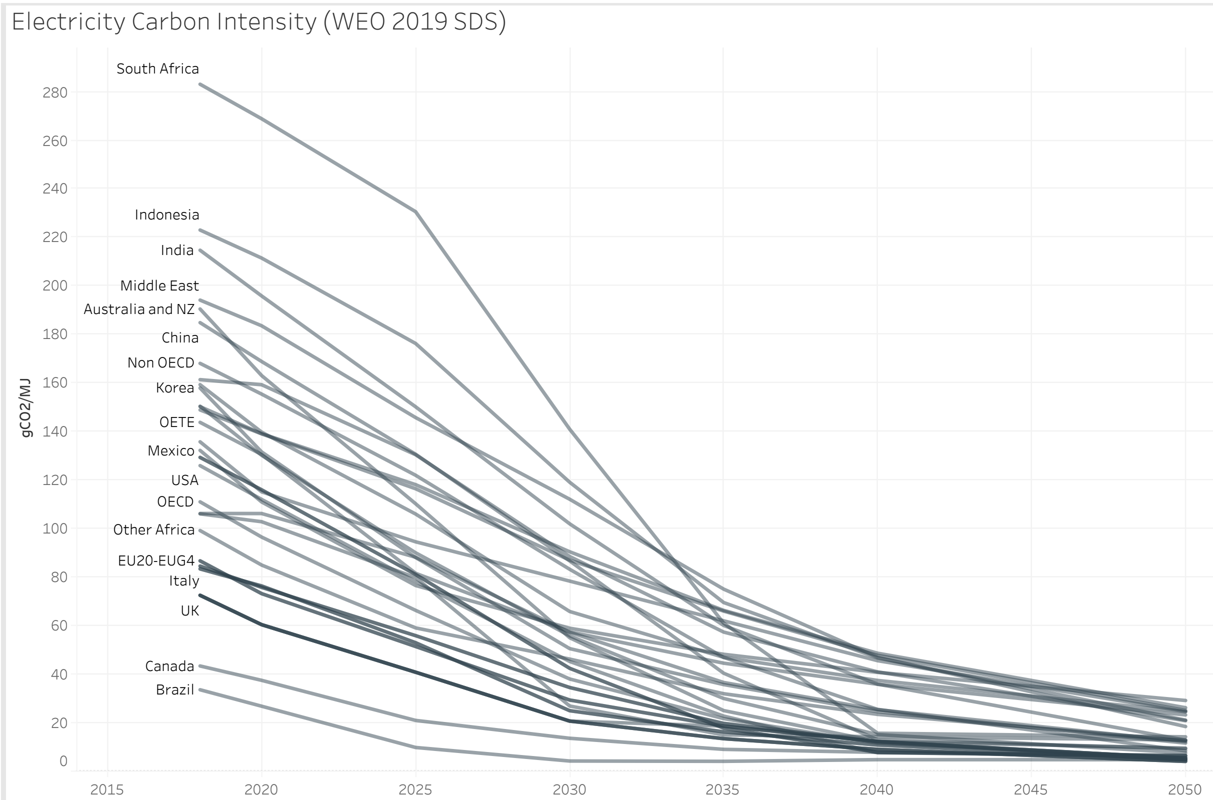
CO_2 emissions

Unlike other pollutants which are technology specific, CO_2 emissions are calculated based on the carbon intensities of fuels. Additionally, the scope of CO_2 emissions includes well-to-tank (WTT) emissions in addition to tailpipe tank-to-wheel (TTW) emissions. Combining the two gives full well-to-wheel (WTW) CO_2 emissions.

For gasoline, diesel, and natural gas, the following values are used for all regions:

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

The carbon intensity of electricity is sourced from the IEA's World Energy Outlook (WEO) 2019 report. The report estimates electricity carbon intensity for 32 global regions in the years 2018, 2020, 2025, 2030, 2035, 2040, and 2050. Roadmap uses the WEO's Sustainable Development Scenario which assumes significant decarbonization of electricity grid. Any electricity consumption before 2018 uses the 2018 values.



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.

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	Energy intensity as absolute or relative to baseline energy intensity
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
Electricity carbon intensity	Electric grid carbon intensity by year
Alternate fleet estimate	Alternate fleet dataset including sales, stock, and activity

For more detail on how to run a scenario refer to the User Guide.