AASHTO Transportation GHG Calculator Technical Documentation
Draft

Introduction

The Transportation GHG Calculator is a spreadsheet tool for calculating Greenhouse Gas (GHG) emissions at a state level using an approach analogous to that proposed by the Federal Highway Administration (FHWA) in its Notice of Proposed Rulemaking (NPRM) titled "National Performance Management Measures; Assessing Performance of the National Highway System, Greenhouse Gas Emissions Measure." The following sections detail the modeling approach, sources of data, and key assumptions regarding the tool.

Modeling Approach

In the NPRM, overall GHG emissions are calculated based on fuel consumption. The portion of GHG emissions attributed to the National Highway System (NHS) is then determined by multiplying total emissions by the ratio of Vehicle Miles Traveled (VMT) on the NHS to total VMT.

The GHG Calculator calculates base year values for GHG emissions in a similar fashion. It estimates a state's baseline GHG emissions based on consumption of gasoline and special fuels, and uses the ratio of NHS VMT to total VMT to determine NHS GHG emissions. The calculation is summarized in Equations 1 and 2.

$$GHG_{base} = FG_{base} CF_g + FS_{base} CF_s \qquad (1)$$

$$NHSGHG_{base} = \frac{NHSVMT_{base}}{VMT_{base}} GHG_{base} \qquad (2)$$

where:
GHG_{base} = base year CO_2 emissions in metric tons
$NHSGHG_{base}$ = base year CO_2 emissions attributed to the NHS in metric tons
FG_{base} = base year consumption of gasoline in thousands of gallons
CF_g = amount of CO_2 released per gallon of gasoline, in kg per gallon
FS_{base} = base year consumption of special fuels (diesel) in thousands of gallons
CF_s = amount of CO_2 released per gallon of special fuels, in kg per gallon
VMT_{base} = base year vehicle miles traveled
$NHSVMT_{base}$ = base year vehicles miles traveled on the NHS

The tool predicts future GHG emissions by scaling the base year calculations to account for VMT growth and change in fleet fuel efficiency. The calculations are made for four different vehicle types: automobiles; single unit trucks (including buses); combination

trucks; and motorcycles. The tool user can adjust the following when predicting future emissions:

- VMT growth rate, specified as the annual percent increase in VMT
- Percent of work trips made driving alone
- Percent of work trips made by carpool
- Fleet fuel efficiency by vehicle type (not including electric vehicles)
- Percent of vehicles that are electric vehicles (EVs) by vehicle type
- Percent of Non-EVs using gasoline (as opposed to special fuels)

Various other parameters are specified in the tool to support future predictions (e.g., percent of automobile VMT that is work-related), but are not modeled as changing over time.

To predict future emissions the tool first predicts VMT by vehicle type in the base and future years. Base year VMT by vehicle type is estimated by multiplying total VMT by the percent of VMT estimated for the corresponding vehicle type.

For single unit trucks, combination trucks and motorcycles the annual rate of VMT growth is used to determine future VMT, as specified in Equations 3 to 5:

$$VMT\_SUT_{future} = VMT_{base} * VP_{SUT} * (1 + g)^t \qquad (3)$$

$$VMT\_CT_{future} = VMT_{base} * VP_{CT} * (1 + g)^t \qquad (4)$$

$$VMT\_M_{future} = VMT_{base} * VP_{M} * (1 + g)^t \qquad (5)$$

where:
VMT_SUT_{future} = future year VMT for single unit trucks
VP_{SUT} = percentage of VMT by single unit trucks
VMT_CT_{future} = future year VMT for combination trucks
VP_{CT} = percentage of VMT by combination trucks
VMT_M_{future} = future year VMT for motorcycles
VP_{M} = percentage of VMT by motorcycles
g = annual rate of VMT growth, specified as a percent
t = number of years in the future relative to the base year for which the prediction is made

For automobiles, the same growth rate is used, but a further adjustment is made to VMT for work trips made by auto to account for any mode shifts. The approach to calculating future auto VMT is as follows:

- Base year auto VMT for work trips is calculated based on the percentage of VMT for auto and percentage of auto VMT that is work related:
- Base year auto VMT for work trips by mode is calculated using the above data, further adjusted using data on the percent of trips made driving alone and made carpooling. This requires converting percent of trips by mode into percent of VMT by mode.

- Future year auto VMT for work trips by mode is calculated by scaling the base year values for changes in mode and the VMT growth rate.
- Future year auto VMT for non-work trips is calculated based applying the VMT growth rate to the portion of auto VMT estimated to be for non-work trips.
- Future year auto VMT is determined by summing the work and non-work components.

This approach is detailed through Equations 6 to 12.

$$VMT\_A_{future} = VMT\_A\_W_{future} + VMT\_A\_NW_{future} \quad (6)$$

$$VMT\_A\_W_{future} = VMT\_A\_DA_{future} + VMT\_A\_CP_{future} \quad (7)$$

$$VMT\_A\_DA_{base} = VMT_{base} * VP_A * AWP * \frac{DA_{base}}{DA_{base}+\frac{CP_{base}}{AOC}} \quad (8)$$

$$VMT\_A\_DA_{future} = VMT\_A\_DA_{base} * \frac{DA_{future}}{DA_{base}} * (1+g)^t \quad (9)$$

$$VMT\_A\_CP_{base} = VMT_{base} * VP_A * AWP * \left(1 - \frac{DA_{base}}{DA_{base}+\frac{CP_{base}}{AOC}}\right) \quad (10)$$

$$VMT\_A\_CP_{future} = VMT\_A\_CP_{base} * \frac{CP_{future}}{CP_{base}} * (1+g)^t \quad (11)$$

$$VMT\_A\_NW_{future} = VMT_{base} * VP_A * (1 - AWP) * (1+g)^t \quad (12)$$

where:
VMT_A_{future} = future year VMT for automobiles
$VMT\_A\_W_{future}$ = future year VMT for automobiles making work trips
$VMT\_A\_NW_{future}$ = future year VMT for automobiles making non-work trips
$VMT\_A\_DA_{future}$ = future year VMT for automobiles making work trips through driving alone
$VMT\_A\_CP_{future}$ = future year VMT for automobiles making work trips through carpooling
VP_A = percentage of VMT by automobiles
AWP = percentage of automobile VMT made for work trips
DA_{base} = percentage of work trips made driving alone in the base year
CP_{base} = percentage of work trips made carpooling in the base year
AOC = average vehicle occupancy for carpools
DA_{future} = percentage of work trips made driving alone in the future year
CP_{future} = percentage of work trips made carpooling in the future year

To predict future GHG it is necessary to couple the prediction of future VMT with any predictions regarding changes in fuel efficiency. The tool predicts base year and future fuel consumption by vehicle type, and then uses the change in fuel consumption to predict a change in GHG emissions. The fuel consumption calculation is shown below for

autos in the base year. The same approach is used for each vehicle type substituting in the relevant parameter values.

$$GC\_A_{base} = \left(\frac{1-EV\_A_{base}}{AE\_A_{base}}\right) G\_A_{base} \quad (13)$$

$$SC\_A_{base} = \left(\frac{1-EV\_A_{base}}{AE\_A_{base}}\right) (1 - G\_A_{base}) \quad (14)$$

where:
GC_A_{base} = gasoline consumption for autos in the base year in gallons per mile
EV_A_{base} = percent of autos that are EVs in the base year
AE_A_{base} = average fuel efficiency for non-EV autos in the base year in miles per gallon
G_A_{base} = percent of autos non-EV autos that consume gasoline (versus special fuels)
SC_A_{base} = special fuels consumption for autos in the base year in gallons per mile

Once fuel consumption is calculated by vehicle type, the next step is to calculate overall consumption, weighted by VMT for each vehicle type. This is calculated as follows:

$$GC_{base} = GC\_A_{base} * VP_A + GC\_SUT_{base} * VP_{SUT} + GC\_CT_{base} * VP_{CT} + GC\_M_{base} * VP_M \quad (15)$$

$$SC_{base} = SC\_A_{base} * VP_A + SC\_SUT_{base} * VP_{SUT} + SC\_CT_{base} * VP_{CT} + SC\_M_{base} * VP_M \quad (16)$$

where:
GC_{base} = overall gasoline consumption in the base year in gallons per mile
GC_SUT_{base} = gasoline consumption for single unit trucks in the base year in gallons per mile
GC_CT_{base} = gasoline consumption for combination trucks in the base year in gallons per mile
GC_M_{base} = gasoline consumption for motorcycles in the base year in gallons per mile
SC_{base} = overall special fuels consumption in the base year in gallons per mile
SC_SUT_{base} = special fuels consumption for single unit trucks in the base year in gallons per mile
SC_CT_{base} = special fuels consumption for combination trucks in the base year in gallons per mile
SC_M_{base} = special fuels consumption for motorcycles in the base year in gallons per mile

The calculations outlined above are repeated for the future year, resulting in future year gasoline and special fuel consumption. The VMT and fuel consumption predictions are then used to predict future year GHG emissions as detailed in Equations 17 and 18:

$$GHG_{future} = \left(FG_{base} CF_g \frac{GC_{future}}{GC_{base}} + FS_{base} CF_s \frac{SC_{future}}{SC_{base}}\right) \frac{VMT_{future}}{VMT_{base}} \quad (17)$$

$$NHSGHG_{future} = \frac{NHSVMT_{base}}{VMT_{base}} GHG_{future} \quad (18)$$

where:
GHG_{future} = future year CO_2 emissions in metric tons
$NHSGHG_{future}$ = future year CO_2 emissions attributed to the NHS in metric tons
GC_{future} = overall gasoline consumption in the future year in gallons per mile
SC_{future} = overall special fuels consumption in the future year in gallons per mile

Data Sources

Table 1 documents the data sources used to establish default parameter values in the tool. The table shows the variable name, parameter description and data source for each. Also, it notes which parameters are updated based on the selection of state.

Table 1. AASHTO GHG Calculation Tool Data Sources

Parameter	Description	Data Source	Updated by State?
VMT_{base}	Base year VMT	2019 Highway Statistics, Table VM-3	Yes
$NHSVMT_{base}$	Base year NHS VMT		
FG_{base}	Base year gasoline consumption	2019 Highway Statistics, Table MF-21	Yes
FS_{base}	Base year special fuels consumption		
g	Annual VMT growth rate	Average annual growth rate of 1.06% calculated using national data for 2010-2019 using Highway Statistics Table VM-3	No
AOC	Average vehicle occupancy for carpools	Value of 2.34 estimated using 2018 American Community Survey (ACS) Journey to Work data	No
CF_g	CO_2 per gallon of gasoline (kg/gallon)	Energy Information Administration (EIA) estimates published at https://www.eia.gov/environment/emissions/co2_vol_mass.php. Note the tool uses the value for Finished Gasoline for gasoline and Diesel for special fuels.	No
CF_s	CO_2 per gallon of special fuels (kg/gallon)		
VP_A	Percentage of VMT by automobiles	2019 Highway Statistics, Table VM-1	No
VP_{SUT}	Percentage of VMT by single unit trucks and buses		
VP_{CT}	Percentage of VMT by combination trucks		
VP_M	Percentage of VMT by motorcycles		
AWP	Percentage of auto VMT for work trips	Value of 19% estimated based on the 2009 FHWA publication: https://nhts.ornl.gov/2009/pub/stt.pdf	No
DA_{base}, DA_{future}	Percentage of work trips made driving alone in the base and future years	2012-2106 ACS Journey to Work Data. Note the same value is used by default for base and future years.	Yes
CP_{base}, CP_{future}	Percentage of work trips made carpooling in the base and future years		
AE_A_{base}, AE_A_{future}	Average fuel efficiency for non-EV autos in the base and future years	2019 Highway Statistics, Table VM-1. Note these values are adjusted to remove EVs. The value for autos is based on light duty vehicles. The value for single unit trucks combines the single unit truck and bus categories.	No
AE_SUT_{base}, AE_SUT_{future}	Average fuel efficiency for non-EV single unit trucks in the base and future years		

Parameter	Description	Data Source	Updated by State?
AE_CT_{base}, AE_CT_{future}	Average fuel efficiency for non-EV combination trucks in the base and future years	Also note the same value is used by default for base and future years.	
AE_M_{base}, AE_M_{future}	Average fuel efficiency for non-EV combination motorcycles in the base and future years		
EV_A_{base}, EV_A_{future}	Percent of autos that are EVs in the base and future years	A value of 1% estimated for automobiles based on various industry estimates reviewed. Use of EVs for other vehicle types was estimated as 0%. Note the same value is used by default for base and future years. The results are not sensitive to the base year value as the estimated fuel efficiency for non-EV vehicles is adjusted such that the overall fuel efficiency matches the 2019 value obtained from Highway Statistics. However, the results are highly sensitive to the future year value.	No
EV_SUT_{base}, EV_SUT_{future}	Percent of single unit trucks that are EVs in the base and future years		
EV_CT_{base}, EV_CT_{future}	Percent of combination trucks that are EVs in the base and future years		
EV_M_{base}, EV_M_{future}	Percent of motorcycles that are EVs in the base and future years		
G_A_{base}, G_A_{future}	Percent of non-EV autos using gasoline (versus special fuels)	Estimated based on the following 2015 Bureau of Transportation Statistics (BTS) publication: https://www.bts.dot.gov/sites/bts.dot.gov/files/legacy/DieselFactSheet.pdf. Note the same value is used by default for base and future years.	No
G_SUT_{base}, G_SUT_{future}	Percent of non-EV single unit trucks using gasoline (versus special fuels)		
G_CT_{base}, G_CT_{future}	Percent of non-EV combination trucks using gasoline (versus special fuels)		
G_M_{base}, G_M_{future}	Percent of non-EV motorcycles using gasoline (versus special fuels)		

Key Assumptions

The following are important assumptions regarding the calculation tool:

- The tool is intended for testing the sensitivity of GHG predictions to various inputs. It does not provide an authoritative calculation of GHG emissions. Various parameters used by the tool may be different from those established by FHWA in implementation of the proposed rule.
- Predictions of future GHG emissions are made by scaling a base year value, 2019 by default. Thus, the predictions are highly sensitive to the base year value.
- Tool users should carefully review the default parameter values, particularly those that do not update automatically based on the state selected. GHG predictions are particularly sensitive to changes in VMT growth, fuel efficiency and EV use.
- The tool does not attempt to predict changes in NHS versus non-NHS fuel consumption or VMT. The base year value is used to determine the percentage of total emissions that can be attributed to the NHS.