Methodology to calculate greenhouse gas emissions using the Motor Vehicle Emission Simulator

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Introduction

This document summarizes the methodology used to calculate greenhouse gas emissions for the DRCOG metropolitan planning organization area, using emission rates from the Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES).

MOVES is a state-of-the-science emissions modeling system that estimates air pollution emissions for criteria air pollutants, greenhouse gases and air toxics. MOVES estimates emissions from on-road vehicles such as cars, trucks and buses, accounting for the phase-in of federal emissions standards; vehicle and equipment activity; fuels; temperatures; humidity; and emission control activities such as inspection and maintenance programs.

In Colorado, the Air Pollution Control Division, a branch of the Colorado Department of Health and Environment, develops the locally defined inputs to MOVES, which is run to establish over 47,000 unique emission rates for each combination of month, hour, road type, speed and vehicle type. The emission rates are then multiplied by distances, total vehicle volumes, volumes per time period, and speeds per time period outputs from DRCOG's Focus travel demand model in a relational database, resulting in a greenhouse gas emissions inventory of surface transportation.

To develop baseline and compliance greenhouse gas emission inventories for the state's Greenhouse Gas Planning Standard, Air Pollution Control Division staff created versions of relational databases for each compliance year (2030, 2040 and 2050) and provided them to DRCOG. Air Pollution Control Division staff trained DRCOG staff on the methodology to perform the greenhouse gas emissions analysis on Feb. 23, 2022, and, per agreement, is authorized to perform the greenhouse gas emissions analysis for compliance with the rule. In the event of an update to the MOVES relational database, Air Pollution Control Division staff will notify DRCOG staff when there are updates to the MOVES relational database including input assumptions. DRCOG staff will be retrained as necessary to perform greenhouse gas emissions analysis.

The MOVES documentation that follows was distributed by the Colorado Department of Transportation and has not been modified by DRCOG staff. It describes the inputs and methodology used to create the MOVES relational databases.

COLORADO
Department of Transportation
Division of Transportation Development

2025 MOVES4 Modeling and Greenhouse Gas Emissions Calculation Methodology

To: Transportation Commission
From: Sabrina Williams - CDOT and Dale Wells - CDPHE
Date: December 22, 2025

Subject: CDOT Greenhouse Gas Transportation Planning Standard — 2025 MOVES4 Modeling and Greenhouse Gas Emissions Calculations Methodology Documentation.

Appendix C.1 - Introduction:

This document summarizes the methodology used to calculate greenhouse gas (GHG) emissions for demonstrating compliance with the CDOT Greenhouse Gas (GHG) Transportation Planning Standard (Standard). Previous GHG emissions calculations to support CDOT were conducted by the Air Pollution Control Division (APCD). This methodology represents a coordinated approach between CDOT and APCD's modeling teams to represent likely future on-road GHG emissions as accurately as possible. The approach was also agreed upon by the Statewide Model Coordination Group (SMCG). Several refinements and improvements were made compared to the previous methodology for calculating GHG emissions due to the availability of new models, data and assumptions. All data and files utilized in the GHG emissions analysis methodology were reviewed by an individual other than the person who developed the data and/or performed the modeling as documented throughout.

The process for calculating GHG emissions begins with generating emission rates using the EPA's Motor Vehicle Emissions Simulator Model (MOVES). The GHG emissions rates developed in MOVES are the same statewide and applied consistently between all agencies to calculate mass total GHG emissions for a compliance area. The emission rates are multiplied by the vehicle miles traveled (VMT) from the Travel Demand Model (travel model) at the link level for individual hours of the days based on the observed vehicle mix from CDOT's statewide Automated Traffic Recorder (ATR) station network within a Microsoft (MS) Access relational database. The result of querying the database is the predicted total mass emissions of GHGs for the roadways represented in the travel model for an average weekday. This requires a series of data analysis and post-processing steps to correctly compile these three main parameters (emissions rates, travel behavior, vehicle mix) into compatible formats within the database.

In 2025 the three significant new considerations for how GHG emissions are calculated for the purposes of an agency demonstrating compliance with the Standard were adopted by consensus through the Statewide Model Coordination Group (SMCG). These considerations involve updates to (1) vehicle emissions rates, (2) vehicle mix assumptions, and (3) the number of vehicle classes considered.

Each step in the emissions calculation process results in standalone datasets (emissions rates, vehicle mix, travel modeling) that are created independently, but compiled in a manner that allows this data to interface with each other through relational database software (MS Access) that calculate total GHG mass emissions for a compliance agency. All data used in the emissions analysis developed by an individual (or agency) was then independently reviewed by another individual (or agency) for data validity and accuracy prior to incorporation into the final GHG emissions calculations methodology. In addition to the analysts and reviewers noted throughout, all SMCG member agencies were extended the opportunity to perform additional data review at each step in development of the emissions calculations, including contributing to the underlying framework that established the methodology and resultant procedures.

Appendix C.2 - Vehicle Emissions Rates

Performed by: Sabrina Williams-CDOT

Reviewed by: Dale Wells-CDOT

New GHG Rates were required to incorporate the State Interagency Coordination Team (IACT) determination, as defined under 2 CCR 601-22 Section 1.44, May 5, 2025 that the CDOT Department of Accounting and Finance (DAF) projections on future EV adoption be used in the GHG emissions rates development. The previous GHG emissions rates were developed using asserted adoption curves of early, mid and late term EV adopters annually with individual forecasts for passenger vehicles and SUVs/light-duty trucks through 2050. CDOT DAF, as part of CDOT's 10-Year Plan development, created a forecast of expected revenue through the year 2050. As part of their revenue forecasting effort, DAF also generated a forecast of light-duty EV fleet growth in Colorado (since revenue from EVs is different from revenue from fossil-fueled vehicles). DAF's forecast estimated 950,000 light-duty EVs in Colorado in 2031, with an estimate of 95% of light-duty vehicles being EVs in 2050.

Separate EV adoption rates were initially developed for passenger cars and SUVs/light-duty trucks as at that time very few EV SUVs/light-duty trucks were available for purchase and it was unknown when additional electrified SUVs/light-duty trucks would be commercially available. Since the time the initial EV planning assumptions were used to develop the original GHG rates, numerous electrified SUV make and models are now commercially available and auto manufacturers continue to release additional EV SUVs for sale. Furthermore, manufacturers have indicated that electrified light-duty trucks will become more broadly available in future years. The Colorado Energy Office (CEO) has completed numerous studies on likely future EV adoption for planning purposes such as EV charging infrastructure needs. These studies also project greater levels of electrification of these larger passenger vehicles within the next five years. Given that a significant percentage of passenger vehicles registered in the state are classified as SUVs and light-duty trucks, the earlier SUV/light-duty truck EV adoption rates was adjusted to reflect the quicker levels of EV adoption now expected. Therefore, in future years the rate of EV adoption is assumed to be the same between passenger cars and SUVs/light-duty trucks in developing the new GHG rates whereas previously they differed.

Appendix C.3 - Vehicle Mix Assumptions

Performed by: Juan Robles-CDOT

Reviewed by: Sabrina Williams-CDOT, Dale Wells-CDPHE

Overview

The vehicle mix represents the type (i.e. motorcycles, passenger cars, SUVs, vans, trucks, etc.) of vehicles operating on a roadway. The GHG emissions rates are highly variable by vehicle class and generally increase with the size of the vehicle. For example, passenger cars emit significantly less GHGs per vehicle mile traveled (VMT) than heavy-duty trucks. While travel demand models forecast total on-road travel behavior, including trips from commercial vehicles, no travel demand model in the state is calibrated for commercial travel accurately enough to properly assign the on-road vehicle mix. Therefore, the real-world observed vehicle mix used to calculate GHG emissions for the Standard is developed from traffic observations (counts) collected by CDOT's vehicle count stations.

Vehicle mix is assigned from ATR data using both continuous and short-duration counts stratified by hour of the day, the 13 Federal Highway Administration (FHWA) vehicle classifications as well as roadway and urban or rural area type updated for more recently observed years. Each ATR station's counts were used in conjunction with VMT weighting for the roadway to develop a ratio of vehicle types by hour for all of the major roadway types in Colorado. The VMT-weighting of the counts is a refinement of the previous vehicle mix assignment that used unweighted (straight) counts in the previous emissions calculations. The VMT-weighting method was developed by CDOT and APCD in order to better reflect the vehicle mix outside the Front Range where the majority of ATR stations are located. Furthermore, for the 2025 vehicle mix used to calculate GHG emissions rates, post-pandemic (2023) vehicle classification counts were used. In the previous GHG emissions calculations methodology, pre-pandemic (2017-2019) vehicle classification counts were used. SMCG determined that an update to post-pandemic vehicle classification counts should be made statewide to the emissions calculation methodology in order to more accurately reflect the vehicle mix that is currently present on roadways in the state as transportation behavior has altered since COVID due to factors including increased remote employment and land use changes.

ATR Count Data Methodology

To assign the vehicle mix percentages by roadway functional category, a total of 316 statewide count stations that collect hourly classification data were used. Of these count locations, 75 of them are permanent traffic recorders (ATRs), and 241 were short-term counts for the years 2022 and 2023. The 13-bin FHWA hourly counts were then grouped into the five Highway Performance Monitoring System (HPMS) class groups used in MOVES to calculate emission rates (passenger vehicles [including SUVs and light-duty trucks], motorcycles, buses, single unit heavy-duty trucks and combination heavy-duty trucks)

To calculate the vehicle mix fractions or percentages for each functional class by individual hours, the VMT-weighted sum of all hourly volumes from each class was divided by the total number of counts for each class. This means that ATR stations have a larger weight than short-term count locations because there are many more hourly counts available from ATRs, and that count stations with higher volumes or VMT have a higher weight than stations with low volumes or VMT.

A simplified example would be if the number of total individual hourly volumes at an ATR station were 20,000 vehicles and 17,000 vehicles were observed to be passenger vehicles and 1,000 vehicles were single unit (SU) trucks. In this case, the percentage of passenger vehicles for that station in that individual hour is assigned to be 85% and the fraction of SU trucks would be 15%.

Figure C-1 below shows percentages for the Urban Freeways and Expressways functional category with reliance on 11 ATRs. The average percentages for this class are shown in green and the percentages for each of the ATRs are below the green bar. Only the aggregated values for the entire area type and roadway functional classification are used to calculate emissions for the state, the individual data shown for each ATR station is used in the calculation of average vehicle mix percentages.

Figure C-1. Example illustrating calculation of vehicle mix percentages as a weighted average of count data from multiple locations

Sta_ID	Rural_Urban	Func_Class	Average VMT	M-cycles	Pass_veh	Buses	SU	Combo
	Urban	**(2) Freeway & Ex**	109,926	**0.17%**	**97.37%**	**0.13%**	**1.25%**	**1.09%**
000003	Urban	(2) Freeway & Expr	134,451	**0.19%**	**97.38%**	**0.06%**	**1.12%**	**1.25%**
000004	Urban	(2) Freeway & Expr	168,873	**0.07%**	**98.27%**	**0.29%**	**0.76%**	**0.61%**
000503	Urban	(2) Freeway & Expr	57,247	**0.10%**	**98.96%**	**0.07%**	**0.50%**	**0.37%**
000504	Urban	(2) Freeway & Expr	246,762	**0.18%**	**97.05%**	**0.23%**	**1.53%**	**1.02%**
000506	Urban	(2) Freeway & Expr	91,498	**0.13%**	**97.97%**	**0.10%**	**1.24%**	**0.56%**
100331	Urban	(2) Freeway & Expr	131,878	**0.20%**	**98.27%**	**0.20%**	**0.85%**	**0.48%**
103608	Urban	(2) Freeway & Expr	104,847	**0.11%**	**98.44%**	**0.09%**	**0.72%**	**0.64%**
103684	Urban	(2) Freeway & Expr	81,433	**0.12%**	**89.91%**	**0.25%**	**3.38%**	**6.34%**
103712	Urban	(2) Freeway & Expr	11,012	**0.10%**	**89.71%**	**0.11%**	**3.29%**	**6.78%**
105548	Urban	(2) Freeway & Expr	164,048	**0.19%**	**97.45%**	**0.07%**	**1.22%**	**1.08%**
107556	Urban	(2) Freeway & Expr	121,040	**0.13%**	**96.99%**	**0.10%**	**1.77%**	**1.02%**

Of the seven roadway functional categories:

(1) Interstate

(2) Freeway & Expressway

(3) Other Principal Arterial

(4) Minor Arterial

(5) Major Collector

(6) Minor Collector

(7) Local

CDOT does not collect classification data on Minor Collectors, Ramps or Local roads that would permit the calculation of accurate mix percentages for these roadways. Thus, there is no vehicle classification count data available at a statewide level for these roads. However, travel models must account for vehicle travel for all road types in the state to accurately predict passenger trips and associated VMT whose emissions need to be accounted for. CDOT and APCD determined the most suitable approach for assigning the vehicle mix on these access roads for the purposes of calculating GHG emissions was to assign the same vehicle mix as the most similar roadway functional classification for which vehicle classification was available. In this case, functional classes six and seven would use the rates from Major Collectors.

The result is a compiled table of the observed individual hourly vehicle mix by HPMS category for the seven roadway functional classifications that are represented in the travel modeling for a GHG compliance area.

The vehicle mix is applied to the travel model run data in the MS Access database that calculates the mass total emissions and is not considered directly within the MOVES modeling to develop the GHG emissions rates as discussed later in the documentation of the GHG emissions analysis methodology.

Appendix C.4 - Vehicle Classes Considered

Performed by: Mobility Analysis Section-CDOT

Reviewed by: Sabrina Williams-CDOT, Juan Robles-CDOT

The original GHG rates developed in MOVES for use in prior analyses to demonstrate compliance with the standard had unique rates for six HPMS vehicle categories: motorcycle, passenger cars, passenger trucks, buses, single unit heavy trucks, and combination heavy trucks. These GHG emissions rates by HPMS category are applied to the travel model data in the MS Access database in conjunction with the observed vehicle mix fractions (observed vehicle classification counts) to calculate total mass GHG emissions for a compliance area. However, Division of Transportation Development Mobility Analysis Section staff realized that because vehicle classification counts are recorded by the number of axles and length of a given vehicle, the CDOT count network often records SUVs and light-duty trucks as passenger cars. Furthermore, in MOVES the type of vehicles are not grouped by the body style of a vehicle, rather by similar characteristics of the engines and associated emissions profiles. This results in many vehicles that are commonly thought of as passenger vehicles, such as wagons and crossovers, being considered to be passenger trucks in the MOVES model.

To more accurately account for the number of larger passenger vehicles and to minimize the discrepancy between the CDOT count network's data collection mechanism and the MOVES model vehicle source types, a refinement was made to the number of vehicle classes considered in the GHG emissions calculations to combine passenger cars and SUVs/light-duty trucks to reflect total passenger vehicles. This was performed by aggregating the observed vehicle classification counts to a new HPMS25 vehicle category representing all passenger vehicles instead of differentiating between passenger cars and SUVs/light-duty trucks. This resulted in reducing the number of HPMS classes considered in the MOVES model to develop the updated GHG emissions rates from six to five categories of vehicles: motorcycles, passenger vehicles, buses, single-unit heavy trucks, and combination heavy trucks.

The refinements to the number of vehicle classes considered results in an increased representation of SUVs/light-duty trucks and their associated GHG emissions in the state that more accurately depicts present real-world observed conditions. Furthermore, the approach of representing all passenger vehicles as a single HPMS category is now consistent with the manner in which CDOT reports HPMS data for the state.

Appendix C.5 - MOVES4 GHG Emissions Rates

Performed by: Sabrina Williams, CDOT

Reviewed by: Dale Wells, APCD-CDPHE

Overview

Incorporating the DAF future EV planning assumptions required new emissions rates to be developed in MOVES. Emissions rates were generated using the MOVES version 4.1.2 (MOVES4). Previously MOVES version 3.0.1 (MOVES3) was used to generate the original GHG emissions rates. The change in GHG emissions rates specific to changing to model versions is minimal due to the previous and continued high levels of EV/ZEV adoption assumed in future years, which is discussed in later sections. For more information about GHG modeling using MOVES, see the [Using MOVES for Estimating State and Local Inventories of On-road Greenhouse Gas Emissions and Energy Consumption] guidance document. The MOVES4 Run Specifications used to generate the GHG emissions rates may also be found in later sections.

MOVES4 Run Specifications

The run specification (RunSpec) parameters outlined below were used to calculate GHG emission rates with MOVES. CDOT performed the MOVES4 modeling to develop the new GHG emissions rates and model results and inputs were reviewed and verified by APCD for accuracy. The MOVES modeling methodology is largely consistent with APCD's previous process to calculate GHG emissions except where noted.

The three modeled years: 2030, 2040, and 2050, used the same run specifications except for where specified (e.g., the year being modeled). Each of the three modeled years has five related run specifications to separate the emission rates by vehicle type, as described in the On-road Vehicles section, i.e., five MOVES runs per compliance year. This denotes a change from the previous GHG emissions rates that were generated using six model runs to represent vehicle types by aggregating passenger cars with SUVs and light-duty trucks into a single MOVES run. When used for modeling compliance with the Standard the GHG emissions rates are applied identically between an agency(s) baseline plan and compliance plan demonstrations, e.g., there is no emissions benefit given to a compliance demonstration for future EV/ZEV adoption. If an MPO or CDOT were to develop a project in a long-range transportation plan specific to switching vehicle types or vehicle fuel types in a future year, this will be revisited by SMCG for consideration on how to best represent these types of planning actions.

Scale

The "Scale" parameters define the model type (on-road or non-road), domain/scale, and calculation type.

Model Type

On-road was the model type selected. This estimates emissions from motorcycles, cars, buses, and trucks that operate on roads.

Non-road/off-network emissions were not included. These emissions are from equipment used in applications such as recreation, construction, lawn and garden, agriculture, mining, etc. and are outside of the scope of this analysis.

Domain/Scale

MOVES allows users to analyze mobile emissions at various scales: National, County, and Project. While the County scale is necessary to meet statutory and regulatory requirements for State Implementation Plans (SIPs) and transportation conformity, either the County or National scale can be used for GHG inventories at the federal level. EPA recommends using the County scale for GHG analysis.

The County scale allows the user to enter locally-specific data through the County Data Manager whereas under the National Scale only MOVES default values are used. Providing local data significantly improves the precision of the modeling results and allows the MOVES users to better evaluate future planning scenarios. Therefore, the County Scale was used.

County Scale in MOVES can be used to model a single county, or a larger representative group of counties such as a nonattainment area or entire state that share common emissions characteristics such as fuel types and blends, emissions testing programs, vehicle age and other considerations. For this modeling, Adams County was used as the representative county on MOVES to develop the statewide GHG emissions rates. All non-default inputs in MOVES4 used in the County Data Manager are representative of the most currently available statewide vehicle data compiled by APCD for EPA's National Emissions Inventory (NEI) Reporting, with the exception of future EV/ZEV adoptions rates at the direction of IACT.

Calculation Type

MOVES has two calculation types - Inventory (total emissions in units of mass) or Emissions Rates (emissions per unit of distance for running emissions or per vehicle for starts and hotelling emissions) in a look-up table format that must be post-processed to produce an inventory. Either may be used to develop emissions estimates for GHGs.

The Emission Rates calculation type was used. Emissions Rates calculation type requires more post-processing; however, this also allows for a consolidated set of GHG emissions rates that can be used statewide by any GHG compliance agency with minimal emissions modeling required from an MPO. Furthermore, this method provides for not needing to rerun MOVES if there is a change to an agency's travel model.

Time Span

The “Time Span” parameters define the years, months, days, and hours that emissions are calculated.

When Emission Rates is specified in the RunSpec, users may choose to approach the selection of options in the Time Spans Panel differently than when running MOVES in Inventory mode. For example, when modeling running emission rates, instead of entering a diurnal temperature profile for 24 hours, users can enter a range of 24 temperatures in increments that represent the temperatures over a period of time. By selecting more than one month and using a different set of incremental temperatures for each month, users could create a table of running emission rates by all the possible temperatures over an entire season or year.

When using Emission Rates instead of Inventory, the time aggregation level is automatically set to Hour and no other selections are available. Pre-aggregating time does not make sense when using Emission Rates and would produce emission rates that are not meaningful. However, the year, month, and day must still be specified and will affect the emission rates calculated.

The time span parameters specified in the following subsections were also used because the travel model outputs represent an average weekday. These daily emissions are then translated into annual emissions in the final step of the emissions calculation process.

Years

The County scale in MOVES allows only a single calendar year in a RunSpec. Users who want to model multiple calendar years using the County scale will need to create multiple RunSpecs, with local data specific to each calendar year, and run MOVES multiple times.

The years used were 2030, 2040, and 2050. Emission rates for each of these years were calculated separately. This accounts for information such as a changing age distribution of vehicles, fleet turnover and their corresponding fuel types and fuel efficiencies.

Months

MOVES allows users to calculate emissions for any or all months of the year. If the user has selected the Emission Rates option, the Month can be used to input groups of temperatures as a shortcut for generating rate tables for use in creating inventories for large geographic areas.

The months used were January and July to match the previous modeling by APCD. These represent winter and summer months and generally the extremes in annual weather conditions. This accounts for changes in fuel efficiency between warm and cold temperatures throughout the year. The arithmetic averages of emission rates from January and July were used for the final emissions inventory to represent an annual average GHG emissions rate.

Days

Weekdays and weekend days can be modeled separately in MOVES. MOVES provides the option of supplying different speed and VMT information for weekdays and weekend days to allow the calculation of separate emissions estimates by type of day.

The days used were weekdays to match the TDM output data. These represented the emission rates for an average weekday. The results are annualized in one of the final steps for calculating the GHG emissions to approximate a full year.

Hours

The hours used were all 24 hours of the day (i.e., clock hours ending at 1:00 AM, 2:00 AM, 3:00 AM, etc.). These represent the emission rates for individual hours of a day. This accounts for changes in fuel efficiency between warm and cold temperatures throughout the day.

Geographic Bounds

The “Geographic Bounds” parameter defines the county(s) used. For a county-scale run, only one county can be selected per RunSpec. The county used was Adams County, Colorado; however, any county in Colorado could have been selected as the MOVES modeling defined input parameters such as the vehicle age used to estimate emission rates using statewide data.

On-Road Vehicles

MOVES describes vehicles by a combination of vehicle characteristics (e.g., passenger car, passenger truck, light commercial truck, etc.) and the fuel that the vehicle is capable of using (gasoline, diesel, etc.). This is required to specify the vehicle types included in the MOVES run.

The “On-road Vehicles” parameter defines the source types (i.e., vehicle types) and their fuels (gasoline, diesel, electricity, etc.). All combinations of vehicle types and fuels available in MOVES4 were used to calculate the emission rates; except that no EV/ZEVs are assumed for buses or commercial vehicles. The process for assigning what vehicle types are represented in the model run has been refined from the previous method that used separate MOVES runs to represent passenger cars vs. SUVs and light-duty trucks. The MOVES model runs used in the GHG rates update now match the MOVES HPMS types defined in the model that aggregates all passenger vehicles into a single category (HPMS=25).

Table C-1 illustrates the HPMS categories.

Table C-1. Composition of vehicle types used for MOVES emissions modeling

MOVES Vehicle Source Type	HPMS Name	HPMS (Current)	HPMS (Previous)
Motorcycle	Motorcycles	10	10
Passenger Car	Light-Duty Vehicles	25	20
Passenger Truck	Light-Duty Vehicles	25	30
Light-Commercial Truck	Light-Duty Vehicles	25	30
Other Buses	Buses	40	40
Transit Bus	Buses	40	40
School Bus	Buses	40	40
Refuse Truck	Single Unit Trucks	50	50
Single Unit Short-Haul Truck	Single Unit Trucks	50	50
Single Unit Long-Haul Truck	Single Unit Trucks	50	50
Motor Home	Single Unit Trucks	50	50
Combination Short-Haul Truck	Combination Trucks	60	60
Combination Long-Haul Truck	Combination Trucks	60	60

Road Type

The Road Type in MOVES is used to define the types of roads that are included in the run. There are four categories of road types in MOVES used to represent onroad emissions and they are separated between urban vs. rural and ramp-controlled (Interstates) vs. non ramp-controlled (local roads). Assignment of the correct road type when calculating emissions is important because in MOVES the vehicle drive cycles assumed in the model are variable by road type, e.g., MOVES assumed more stop and go traffic on local roads associated with intersection controls than interstates, as well as area type, e.g., MOVES assumes a greater level of congestion on local roads in urban areas than rural areas. MOVES also has an option for Off-Network road types which would be associated with vehicle emissions not occurring in traffic, e.g., idling vehicles at a large transit station. All road types were selected in MOVES. The Off-Network road type must be selected for MOVES to execute in Emissions Rate mode, but was not used in the emissions calculations as they are not on-road emissions.

Pollutants and Processes

The Pollutants and Processes Panel allows users to select from various pollutants, types of energy consumption, and associated processes of interest. In MOVES, a pollutant refers to particular types of pollutants or precursors of a pollutant but also includes energy consumption choices. Processes refer to the vehicle mechanism by which emissions are released, such as running exhaust or start exhaust. Users should select all relevant processes associated with a particular pollutant to account for all emissions of that pollutant. Generally, for this project, that includes running emissions, e.g. emissions processes associated with vehicle start-ups, extended idling and refueling occur on Off-Network road types in MOVES.

The CO_2 Equivalent pollutant is the sum of the global warming potential of Carbon Dioxide (CO_2) and all other greenhouse gases expressed as a unit CO_2 Equivalents. (CO_2e) is the pollutant of interest in MOVES as it accounts for all greenhouse gas emissions considered in MOVES. MOVES requires several other prerequisite pollutants for CO_2e, e.g., methane; whose individual global warming potentials are calculated within the model and appropriately summed with CO_2 and reported as CO_2e.

General Output

The General Output parameters define the output database, units, and activity.

Output Database

Results from the five related HPMS RunSpecs for a given analysis year (2030, 2040, 2050) can be stored together in a single output database for convenience, or separate databases can be created for each run. The RunSpecs must have the same units and aggregation or MOVES will not execute. A different output database is required for each year and varying MOVES RunSpec. A consistent and informative naming convention for the output database assists in file housekeeping. Five output databases were used for each year modeled representing a single HPMS category for that year. Each output database contained results for the modeled year and vehicle HPMS category.

Units

Users can select from any of the mass unit selection options but should generally choose a unit whose magnitude is appropriate for the parameters being analyzed.

The units selected in the MOVES RunSpecs are grams for mass, joules for energy, and miles for distance.

Activity

MOVES allows the user to select multiple activity output options. As Emissions Rates were selected MOVES automatically reports emissions in mass units per distance traveled (grams/VMT) for each month and hour selected in the MOVES Time Spans panel for each Road Type selected in MOVES.

Output Emissions Detail

This panel allows the users to make selections that will additionally disaggregate the data beyond what is automatically reported by MOVES. Certain selections are automatically made by MOVES based on the RunSpec definition and cannot be unselected.

No optional details were selected in this panel as the outputs automatically reported by MOVES for these RunSpecs contain sufficient detail for calculating GHG emissions in this manner.

Input Database (Formerly the County Data Manager)

The previous panels in MOVES defined the RunSpec and the format of the output data. The next step is to create the input database where files with local data are imported.

The RunSpec parameters selected in the other panels in MOVES define the file structure and required data for the input database and constrain all files imported into MOVES to this structure or errors are generated and the model will not execute. Therefore, it is recommended that the MOVES user make this Input Database the last panel used in the MOVES graphical user interface (GUI) as any alterations to the RunSpec can result in needing to recreate its settings.

One input database was created for each model year for each vehicle HPMS category; a total of 15 MOVES model runs. Data is imported into the input database for each MOVES run, as specified below.

Age Distribution

The Age Distribution in MOVES represents the distribution of the age of each vehicle type in MOVES from 0-30 years old (vehicles whose model years are 31 years and older). The age distribution is a critical input in MOVES as this directly assigns the specific vehicle model years and vehicle characteristics, e.g., fuel types and associated emissions rates. MOVES allows the user to import locally specific data as was performed in this analysis. APCD develops locally specific age distributions from all vehicles registered in the state every three years for the EPA's National Emissions Inventory (NEI) reporting at the county and statewide level, as well as for the Denver Metro/North Front Range 8-hr Ozone Nonattainment Area. For this analysis, the statewide age distribution for the 2024 NEI reporting was imported into MOVES4 except for long-haul commercial vehicles. National default values were used for long-haul commercial vehicles as a significant portion of these vehicles in the state are registered elsewhere in the country.

Average Speed Distribution

Vehicle tailpipe emissions rates are highly affected by the speed the vehicle is traveling. At lower speeds associated with congestion emissions rates are higher and rates decrease until vehicles are traveling at speeds of approximately 55 miles per hour (mph) where at that point emissions rates begin to increase again. MOVES requires an Average Speed

Distribution be imported to perform a model run. This distribution is an important input in Inventory Mode as it represents the detailed information concerning the on-road speeds of vehicles and related emissions rates by road type, hour of the day, day of the week, and month of the year. In Emissions Rates mode, however, the average speed distribution is not used and for this analysis national default values were used.

Fuel

The fuels data in MOVES assigns the specific fuel formulations, including chemical properties, for all petroleum vehicles as well as the fuel types for each vehicle type by model year including representation of EV/ZEVs in the model through the Alternative Vehicles Fuels and Technologies (AVFT) file. For the GHG analysis, default fuel values were used with the exception of the AVFT data.

The AVFT file specifies the fraction of each fuel used by a vehicle type, e.g., gas, diesel, ethanol and electricity, for vehicle model years 1960-2060. It is important to specify these fractions by model year as this provides a more accurate estimate of the fuel economy standards and emissions improvements associated with fleet turnover as older higher emitting vehicles are retired and replaced with lower emitting vehicles than assuming an average fuel mix for an entire vehicle type in MOVES.

In a MOVES run, vehicle data is only considered for the same vehicle model year as the analysis year selected in the RunSpec and and the previous 30 vehicle model years, i.e., the fuel mix considered in a specific run is assigned from the Age Distribution in MOVES.

Although EV/ZEVs have zero GHG emissions, these vehicles do have emissions of other pollutants, such as particulate matter, and should be represented within MOVES. Therefore, future EV/ZEV planning assumptions are directly considered within MOVES and there is no “zeroing” out of EV/ZEV VMT, because that VMT corresponds to a GHG tailpipe emissions rate of zero. For this analysis the AVFT file used the same motor vehicle registration data for the 2024 NEI as the Age Distribution through vehicle model year 2024 after which the DAF EV planning assumptions for light-duty vehicles were incorporated to represent future EV adoption levels. MOVES4 contains default values for future EV adoption for commercial vehicles; however, this data was not used in the model and no EV/ZEVs were considered for commercial vehicles.

Meteorology

Vehicle emissions rates can vary by temperature and humidity, particularly for criteria pollutants and mobile source air toxics. However, GHG emissions from vehicles relate to atmospheric conditions solely based on a driver’s comfort and their likely usage of air conditioning in a vehicle and resultant impacts to fuel economy. The default values for Meteorology in MOVES represent actual climate data for all individual counties in the nation as collected from the National Climate Data Center. MOVES default data for Adams County, Colorado was used for the months of January and July in the analysis, which is consistent with the RunSpec.

Road Type Distribution

MOVES does not have default data for the Road Type Distribution and it must be created and imported by the user. In Emissions Rates the Road Type Distribution data in a MOVES run does not impact the results and is not an important file in the analysis, but must be present and correctly compiled for the model to run. A Road Type Distribution file was provided by APCD imported in MOVES for the analysis.

Source Type Population

MOVES requires the Source Type Population file to be present in MOVES and there is no national default data available in MOVES. However, this file does not change the results in Emissions Rates as this data is used for calculating vehicle emissions associated with off-network activity, e.g., extended periods of idling at a truckstop or a large number of vehicles congregating at a transit station. As these vehicle emissions are not truly occurring "on-road" they are not accounted for in the analysis or present in the Emissions Rates output files. The Source Type Population was provided by APCD from the 2024 NEI and used in the analysis.

Vehicle Type VMT

The Vehicle Type VMT is required to run MOVES and is very important if Inventory is selected in the RunSpec. However, in Emissions Rates mode this data does not change the results; moreover, a single vehicle classification is considered in this analysis so the VMT considered in MOVES does not vary by vehicle category. Default Vehicle Type VMT data was imported in MOVES for all runs with the exception of the annual HPMS file that was provided by APCD from the 2024 NEI in order for MOVES to run.

Inspection and Maintenance Program

The Denver Metro/North Front Range Ozone Nonattainment Area has a vehicle inspection and maintenance (I/M); i.e., emissions testing program as an emissions reduction strategy in the state implementation plan (SIP) for all or a portion of these nine counties in the state. However, in MOVES there is no GHG tailpipe emissions benefit associated with I/M programs as emissions control devices such as catalytic converters and diesel particulate filters do not reduce emissions of GHGs. In MOVES there is a slight methane credit given to I/M programs associated with evaporative emissions; however, these emissions reductions are insignificant compared to net GHG emissions that are dominated by tailpipe exhaust. The check box for "No I/M Program" was selected since there is not a statewide I/M program and accounting for the minimal GHG emissions credit within the ozone nonattainment area would result in no meaningful change to the results.

MOVES Output Data and Post-processing

Output Database (HeidiSQL)

After MOVES has successfully completed a model run the results are stored in the output database that was created in the RunSpec. The MOVES install package includes HeidiSQL which is an open source database software and results are automatically stored here as well as the data that was imported into the input database for that RunSpec.

The main output file of interest in MOVES for this analysis is the “Rate Per Distance” table. The file associated with each MOVES run contains the emissions rates for the HPMS category being analyzed for the months, road types and pollutants specified in the RunSpec for every individual hour of the day by speed bin. This table was queried in HeidiSQL to select only emissions of CO_2eq as that is the pollutant of interest in the analysis and those results were exported from the HeidiSQL as a .csv file for each MOVES run.

Post-Processing Emissions Rates by Speed and Month

Emissions Rates mode in MOVES does not produce emissions rates associated with speed changes at the level of rates at individual integer speeds in miles per hour values. Rather MOVES aggregates emissions by speed into groups of 16 speed bins with each bin corresponding to a five mile per hour maximum and minimum range of vehicle speeds, e.g., 42.5 mph to 47.5 mph. This results in faster model run times and smaller output files, and could be appropriate in instances where only a qualitative analysis is needed. However, for the purposes of this quantitative analysis a greater level of granularity concerning emissions rates by speeds is needed for GHG emissions results precise enough for accurate comparison to the absolute standards associated with each compliance year.

Previously the emissions rates were post-processed to produce emissions rates in grams per mile at individual integer speeds through interpolation in an additional MS Access database that was separate from the database utilized to calculate total mass GHG emissions for a compliance area. In revising the analysis, the interpolation methodology to develop GHG emissions rates in individual integer mph values remains unchanged, but APCD has consolidated this step into the same MS Access database used by an agency to calculate the total GHG emissions for a compliance area. Average annual emissions rates were similarly generated from a straight average of the emissions rates from the representative months of January and July in MOVES output data in the MS Access database.

Appendix C.6 - Calculation of Mass GHG Emissions

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Reviewed by: Sabrina Williams-CDOT

Total mass GHG emissions for a compliance area are calculated in MS Access databases for 2030, 2040 and 2050 that are developed by APCD and are unique for each MPO/non-MPO area based on the design and structure of each compliance agency’s travel modeling platform as well as the format the travel model runs data is provided.

Each database contains lookup tables for the GHG emissions rates and vehicle mix ratios that are consistent statewide, and the travel model run files specific to each individual agency. There are additional tables in each database that appropriately assign each link a road type from MOVES based on the area type and roadway functional classification based on an agency's travel modeling metadata.

Travel Model Data Considerations

Prior to calculating GHG emissions an agency must remove all links extending outside of their GHG compliance area that are represented in the travel model run. This is performed by a compliance agency splitting any sections of links that may go outside a compliance area in comparison to their boundary in appropriate spatial software, e.g., ESRI geographic information system (GIS) or TransCAD, so that only the portions of the link within a compliance area boundary are considered in the GHG emissions calculations for the agency. Following the splitting of links, the length of those split links must be recalculated. Whether this calculation is done automatically or manually depends on the particular software platform in use. Once the lengths of any split links are calculated, the VMT for the split links can be calculated by multiplying the recently-calculated link length by the predicted travel volumes.

GHG emissions rates are highly variable by vehicle speeds, and to a much lesser extent individual hours of the day based on temperature and use of cooling in the cab of the vehicle. Ideally, some form of dynamic traffic assignment would be used (such as the Simulation-Based Assignment of PTV VISUM) to estimate such within-day variation in travel speed. Static assignment of 24 individual hours would produce similar output data for GHG emissions calculations. Conversely, if an agency's travel model has less than 24 time periods, coordination is required between CDOT, APCD and individual MPOs on an agreed upon process for disaggregating travel model data with predicted vehicle volumes and speeds from time periods representing multiple hours to discrete individual hours. This is particularly important for agencies with a traffic assignment process that contains a single off-peak period representing 22 hours travel behavior in a day. In this instance simply dividing the predicted volumes on a link by the number of hours in the period is likely to greatly underestimate travel volumes during the AM and PM peak shoulders and midday hours, while overestimating travel volumes in nighttime hours. Furthermore, the use of the predicted speed for a link from a four-step model during an off-peak hours is likely to overestimate speeds during the AM and PM peak shoulders and midday hours which results in underestimating emissions during this time of day.

Querying the Database

The MS Access databases developed by APCD each contain numerous queries that run in sequence. These queries assign the correct GHG emissions rates and vehicle mix ratios at the link level through a series of joins. The length of each link is multiplied by the predicted hourly volume to calculate the VMT for that hour that then is multiplied by the vehicle mix ratio and appropriate GHG emissions rate for that vehicle class to calculate the emissions. Emissions for the links are then summed together to calculate the final database output which is daily GHG emissions in short-tonnes for each travel model scenario.

Calculation of Annual Emissions and Modeled Reductions

The emissions in GHG short-tons/day from the MS Access database are extracted into spreadsheet workbooks, e.g., MS Excel, and annualized through multiplying the weekday emissions by 338 to get annual emissions. Standard unit conversions (one US short ton = 0.907185 metric tons) are applied to calculate the GHG emissions in million metric tons (MMT) per year for each agency's baseline and compliance travel model scenarios for 2030, 2040, and 2050. The modeled emissions reduction for each year is simply calculated by subtracting the compliance emissions from the baseline emissions. The modeled emissions reduction is then compared to the agency's reduction target for that compliance year to determine if compliance with the Standard has been demonstrated through modeling or if mitigation is required.