CalEEMod
California Emissions Estimator Model

Appendix C
Emission Calculation Details for CalEEMod

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1 Overview

The California Emissions Estimator Model (CalEEMod) calculates ozone precursors, criteria pollutants, and greenhouse gases (GHG) (collectively referred to as *emissions*) from land use development and linear projects. These emission estimates can be used for quantification and reporting as part of the California Environmental Quality Act (CEQA) environmental documentation. This appendix provides the detailed quantification method, including the underlying equations and supporting documentation for calculating default activity data, emissions, and emission reductions from measures.

Emissions are quantified in three modules within the **Input** component—**Construction**, **Operations**, and **Vegetation**. Each of these modules includes one or more submodules and screens covering a specific emission source (e.g., off-road equipment). This appendix discusses the default data sources and emissions calculations associated with each submodule and screen. Because user inputs in the **Characteristics** and **Land Use** modules inform the emissions calculations, this appendix also addresses these modules. Likewise, this appendix describes the types of emission reduction measures included in the **Measures** module. Figure C-1 illustrates the modules, submodules, and screens that are described in this appendix.

The user is directed to the following additional appendices for further information related to emissions quantification.

- Appendix D, *Technical Source Documentation for Emissions Calculations*: Provides additional technical emissions quantification methods and sources.
- Appendix G, *Default Data Tables*: Provides defaults and emission factors for the estimation of emissions. References to specific data tables within Appendix G are provided throughout this appendix.

The user may also consult the **Construction Calcs** and **Operations Calcs** screens within the **Results** component. These screens present a series of tables with emissions results by source. For example, the **Construction Calcs** screen displays total construction emissions from all sources and then individually by source (i.e., off-road equipment, dust from material movement, demolition, mobile exhaust, on-road fugitive dust, architectural coatings, paving, and electricity consumption). Where applicable, the source tables present emissions by process. For example, emissions from vehicle trips and vehicle miles traveled (VMT) are presented separately within the mobile exhaust table. Users can view the equations and variables underpinning the results by clicking directly on any calculated emissions value in the tables. Users can click the toggles at the top of the screen to display unmitigated or mitigated emissions for the daily or annual condition. Daily emissions can be presented for the winter or summer season. Annual emissions can be presented in pounds, tons, or metric tons (MT). While the emissions displayed in the **Construction Calcs** and **Operations Calcs** screens can also be viewed in the dashboards and **Reports** component, the screens enhance transparency by specifically identifying the equations and variables used by CalEEMod to quantify emissions by source and process.[1]

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[1] As noted in the paragraph, users must click an emissions result to see the equations and variables used in the calculation of that result.

Inputs

Characteristics

- Project Detail
- Pollutants
- Utility Information

Land Use

- Land Use

Construction

- Construction Phases
- Off-Road Equipment
- Off-Road Equipment EF
- Dust from Material Movement
- Demolition
- Trips and VMT
- On-Road Fugitive Dust
- Architectural Coatings
- Paved Area
- Electricity

Operations

Mobile Sources

- Vehicle Data
- Vehicle EF
- Fleet Mix
- Road Dust

Area Sources

- Hearths
- Consumer Products
- Architectural Coatings
- Landscape Equipment

Energy Use

- Energy Use

Water and Wastewater

- Water and Wastewater

Solid Waste

- Solid Waste

Refrigerants

- Refrigerants

Off-Road Equipment

- Off-Road Equipment
- Off-Road Equipment EF

Operations (cont.)

Stationary Sources

- Emergency Generators and Fire Pumps
- Generators/Pump EF
- Process Boilers
- Boilers EF

User Defined

- User Defined

Vegetation

- Land Use Change
- Sequestration

Measures

Emissions Reduction

- Introduction
- Construction
- Transportation
- Energy
- Water
- Waste
- Refrigerants
- Natural Lands
- Area Source
- Miscellaneous

CalEEMod Structure Legend

Components

Modules

Submodules

- Screens

Figure C-1. CalEEMod Structural Elements Described in Appendix C

2 Characteristics Module

The **Characteristics** module includes three screens: **Project Detail**, **Utility Information**, and **Pollutants**. These screens have no calculations and are used to provide information on appropriate default values for subsequent screens. Each screen is briefly described in the following sections. See Section 4.3.1, *Characteristics Module*, of the User's Guide for additional information.

2.1 Project Detail Screen

The **Project Detail** screen summarizes administrative information (e.g., county) from the **Map** component that is relevant to emission quantification. Based on the project location, the screen will display the windspeed and precipitation frequency. Windspeed and precipitation frequency influences the intensity of emission factors related to fugitive dust generated during project construction. CalEEMod includes average annual windspeeds based on hourly data from 1996 to 2006 for various monitoring stations throughout California from the Western Regional Climate Center (2021) (refer to Table G-1). Precipitation frequency represents the average annual days with precipitation greater than 0.1 inch based on data from 2016–2019 for various monitoring stations throughout California (NOAA 2021a) (refer to Table G-2). CalEEMod selects the nearest monitoring station to the project to inform the default windspeed and precipitation frequency. The user should review this information to confirm it is accurate before moving forward.

User input is also required or recommended for the following data fields.

- *Automatic Updates to Default Values*: CalEEMod is a complex information model that requires the user to input a certain level of project detail, with some inputs influencing later dependent defaults. Because the user may have different interests in how these dependencies are handled, the model was built with three update options—always, never, and if not overridden. See Section 4.3.1.1, *Project Detail Screen*, in the User's Guide for additional information.

- *Quantification mode*: The user may quantify emissions for only construction, only operations, both, or neither, by making the appropriate selection from the dropdown menu and toggle. If the user deselects either Construction or Operations, the now-irrelevant data fields on the **Project Detail** screen will be locked and grayed out, prohibiting user input. For example, if Construction is deselected, the "Windspeed" data field will be locked, as it only influences emission factors related to fugitive dust generated during construction. If the user turns off the toggle, thereby deselecting both Construction and Operations, CalEEMod will not quantify emissions and the corresponding modules will be hidden from the Side Navigation Bar.

- *Analysis Level for Defaults*: The analysis level defines the degree of aggregation for mobile source emission factors and various data fields with default values (e.g., Windspeed). Four analysis levels are available for user selection—County, Air District, Air Basin, and Statewide. CalEEMod defaults to County, which provides the most locationally-specific emission factors and defaults. If the user changes the analysis level to one of the other options, the "County" data field will be replaced by a data field for the new analysis level (e.g., Air Basin) with the default value prepopulated based on the project location.

- *Start of Construction*: The construction year influences the intensity of several emission factors, including those for vehicles and equipment. The user should identify the day, month, and year for their first phase of construction. This information will be carried forward to the **Construction Phases** screen.

- *Operational Year*: The operational year influences the intensity of several emission factors, including those for vehicles, equipment, and electricity consumption. The operational year is typically the first year following construction when the project is fully operational.

2.2 Utility Information Screen

The **Utility Information** screen summarizes the electric and gas utility companies for the project based on the project location. The user should confirm the utilities before moving forward. The user may select a different California utility from the dropdown menu. If the project utility is not included in the dropdown menu, the user may select User Defined.

CalEEMod includes electricity intensity factors for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) for many California utilities and will default to those factors when the specific utility is selected. If electricity intensity factors for the selected utility are not available, CalEEMod will default to the statewide grid average intensity.

Electricity emissions can be quantified using emission factors for the latest year with reported data, which is 2019. Alternatively, the user may elect to use forecasted future year carbon intensities by selecting the forecasted factors toggle. Forecasted carbon intensities are only available for utilities that provided data during programming and reflect utility-specific planning considerations, including future integration of renewables. Future year emission factors for these utilities may be available for all programmed operational years (i.e., 2020 through 2050) or only a subset of years (e.g., 2020 through 2030). If a utility provided forecasted emission factors for a subset of years, emission factors for all remaining years are held constant at the values for the last year in which data were provided. For example, the City of Anaheim Public Utilities Department provided forecasted CO_2 factors through 2032. Because 2032 is the last year in which the utility provided data, the 2032 carbon intensity of 267 pounds (lb) of CO_2 per megawatt-hour (MWh) is held constant as the default CO_2 intensity for all years from 2033 through 2050.

As noted above, forecasted electricity emission factors are only available for a subset of utilities (refer to Table G-3). No future year emission factors are available for the statewide default. Where future year data are not available for a utility or year, toggling the “Forecasted Factors” button will not yield any changes to the emission factors shown on the screen. It is also important to note that data provided by utilities is based on their own internal planning projections and may not always yield a reduction in carbon intensity over the prior year.

The selected natural gas utility is provided for informational purposes only and does not influence the carbon intensity of natural gas combustion. Emission factors for natural gas combustion are from the U.S. Environmental Protection Agency (USEPA) (1998a) AP-42 and the California Air Resources Board (CARB) (2020a) (refer to Table G-4).

2.3 Pollutants Screen

CalEEMod quantifies the following pollutants. Definitions of these pollutants are provided in Appendix A, *Glossary*.

- Total organic gases (TOG).
- Reactive organic gases (ROG).[2]

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[2] CalEEMod uses the term volatile organic gases (VOC) when referring to emissions from the application of architectural coatings, consistent with local regulations. VOCs are organic compounds that can evaporate into an organic gas. VOC can be either reactive or non-reactive. Over the years, non-reactive VOCs have been exempted

- Nitrogen oxides (NO_X).
- Carbon monoxide (CO).
- Sulfur dioxide (SO_2).
- Particulate matter (PM) that is 10 microns in diameter or less (PM10).
- PM that is 2.5 microns in diameter or less (PM2.5).
- Biogenic CO_2.
- Non-biogenic CO_2.
- CH_4.
- N_2O.
- Refrigerants (R).
- Carbon dioxide equivalent (CO_2e).[3]

The model automatically selects all pollutants for quantification on the **Pollutants** screen. The user should uncheck any pollutants they do not want quantified before moving forward.

3 Land Use Module

3.1 Land Use Screen

The primary project description data that the user needs to enter is all land use types and sizes that make up the project. CalEEMod contains several land use categories that are mainly based on land use classifications from the Institute of Transportation Engineers (ITE). Further division of some land uses (mainly warehouses) has been added. CalEEMod also contains linear land use types, as defined by the Sacramento Metropolitan Air Quality Management District's Roadway Construction Emissions Model (RCEM). The land use subtype determines default values for numerous data fields throughout the model. The user-defined land use (e.g., User Defined Commercial) does not have any default information, and the user is required to enter all necessary information. Land use types and subtypes identified by the user in the **Start a New Project** splash screen are automatically prepopulated in the **Land Use** screen. Additional land uses can be added by clicking "Add Land Use Type."

Once the land use types and subtypes are defined, the user should provide or review available defaults for the following inputs.

- *Unit*: Different units (e.g., 1,000 square feet [sqft], acre) are available by land use subtype. Depending on the unit selected by the user, CalEEMod may internally convert the input to an alternative unit so that the information is cross-compatible with emission factors and other inputs defined by the alternative unit.

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from regulation. Both VOC and ROG are precursors to ozone, so they are summed in the CalEEMod output under the header ROG.

[3] Represents all CO_2 emissions plus CH_4, N_2O, and refrigerants as adjusted by their corresponding global warming potential (GWP).

- *Size*: This numeric input corresponds with the “Unit” data field to collectively form the size estimate for the land use subtype (e.g., a 200 “Size” is multiplied with a 1,000 sqft “Unit” to equal a 200,000 sqft land use subtype).

- *Lot Acreage*: The lot acreage is used to calculate housing density (for residential land use types) and dust emissions from earthmoving activities during project construction, and to assign construction default data (e.g., off-road equipment). CalEEMod automatically calculates the lot acreage for all non-linear and linear use types based on user inputs for the “Land Use Subtype,” ”Unit,” and ”Size.” Refer to Table G-5.

  The default lot acreage for the residential land use types is based on data from the 2019 Residential Appliance Saturation Survey (RASS) (CEC 2020). Retirement communities and congregate care facilities are assumed to be similar in size to multi-family units. The default for single-family housing land use subtype is inclusive of parking and landscaped area. The model assumes 480 sqft of paved driveway space per dwelling unit (DU) for single-family housing. The remainder of the difference between the total lot acreage and paved driveway space is conservatively assumed to be landscaped area.

  The default lot acreages for other residential land use subtypes and all non-residential land use types are equal to the building footprint and, therefore, do not include any parking or landscape area. The user should review these default acreages and confirm they accurately reflect the total project lot acreage.

  The user should adjust the default acreages if the project is a mixed use, multi-story building. For these projects, the default acreage value for the residential land use subtype should be retained and the acreage values for all non-residential land use subtypes should be zeroed out. If the mixed use, multi-story building includes only non-residential uses, whichever land use subtype has the highest default acreage value should be retained and the acreage values for all other land use subtypes should be zeroed out.

  For linear land use types, there is no default lot acreage based on the inputs for the “Unit” and “Size” data fields (i.e., project site length in miles). This is because no default project site width is assumed for linear land use types, which is needed to calculate the area.

- *Building Square Feet*: The building square footage is used to calculate several operational source emissions and construction-generated emissions from architectural coatings. CalEEMod generates default inputs for residential building square footage based on the 2019 RASS (CEC 2020). Default inputs for non-residential land use subtypes are also available and are based on Table B1 of the U.S. Energy Information Administration’s Commercial Building Energy Consumption Survey (2016) and land use statistics from the South Coast Air Basin (See Appendix D, *Technical Source Documentation for Emissions Calculations*). No building square footage is assumed for linear land use subtypes, Parking land use subtypes with no structure (e.g., Parking Lot land use subtype), and the city park and golf course land use subtypes. Accordingly, CalEEMod reports a 0 value for building square footage for these land use subtypes; the value is locked at 0 and cannot be overridden.

- *Landscape Area*: Landscape area is a required input to calculate operational outdoor water consumption and associated emissions. The area includes water features and all planting and turf areas in a landscape design plan, *including* any special landscape areas (defined in the below bullet) (i.e., do not subtract special landscaping area from landscaping area). The landscape area should not include building footprint, sidewalks, driveways, parking lots, decks, patios, or other hardscapes and non-irrigated areas designed for non-development.

Defaults for the landscape area are only available for the single-family housing land use subtype. The landscape area for this land use subtype (11,713 sqft per DU) is equal to the difference between the total lot area (14,143 sqft per DU) and the combination of the building area (1,950 sqft per DU) and the paved driveway space (assumed 480 sqft per DU). The user must provide the landscaping area for all other land use subtypes. Leaving the input for landscaping area blank will exclude quantification of operational outdoor water consumption and associated emissions.

- *Special Landscape Area*: If defined, this is used to calculate operational outdoor water consumption and associated emissions. The area includes the portion of landscape dedicated solely to edible plants, areas irrigated with recycled water, water features using recycled water, and area dedicated to active play, such as parks, sports fields, golf courses, and places where turf provides a playing surface.

  Unlike the “Landscape Area” data field, inputs for the “Special Landscape Area” data field are not required to enable the calculation of operational outdoor water consumption and associated emissions. However, defining the special landscape area (if any) is recommended, as it will provide for a more accurate quantification of these sources, as discussed further in Section 5.4.1.2, *Annual Outdoor Water Use*.

  CalEEMod assumes zero special landscape area as a default for all land use subtypes except City Park, Golf Course, Elementary School, High School, Junior College (2 yr), Junior High School, University/College (4 yr). For these uses, the special landscape area is equal to the landscape area (i.e., the model assumes 100 percent of the landscape area is classified as special landscape area).

- *Recreational Building Area*: The recreational building area is used to provide a more refined estimate of several operational source emissions and construction-generated emissions from architectural coatings and consumer products. For City Park, Golf Course, and Recreational Swimming Pool land use subtypes, the user should enter in this data field the square footage of only the buildings associated with these land uses (e.g., restrooms/changing rooms, pro-shop).

- *Population*: Project population is used to calculate operational waste generation and associated emissions for residential land use types. Population defaults for residential land use types are from the California Department of Finance (2020) (refer to Table G-6).

- *Description*: If desired, the user may enter a description of the land use type. For example, “ground floor retail in mixed use building A.” This description will be included in the CalEEMod output.

4 Construction Module

The **Construction** module is used to calculate the emissions associated with the construction of a project. Construction can have several different types of sources that contribute to emissions. The sources quantified by CalEEMod are off-road equipment usage, on-road vehicle travel, material movement, demolition, architectural coating, paving, and electricity consumption. Each of these source types is discussed in more detail in the subsequent sections. These emission sources are associated with various types of construction phases. Typical construction phases include demolition, site preparation, grading, trenching, building construction, paving, and architectural coating. The extent to which these phases occur depends on the specific project. For instance, a demolition phase would typically only occur if demolition of existing structures was required. Similarly, trenching only typically occurs if the project requires trenching generally associated with underground utilities. Unique aspects and default assumptions associated with these phases are discussed in the following sections in the context of the different emission source calculations.

4.1 Construction Phases Screen

CalEEMod generates default construction phases and schedule assumptions on the **Construction Phases** screen based on user inputs in the **Land Use** module. Specifically, for non-linear land use types, construction surveys performed by the South Coast Air Quality Management District (South Coast AQMD) are used to define the default phases and durations based on the total project acreage (refer to Table G-7). If the project acreage is in between the acreages in the survey, the next highest acreage tier is used. If the project size defined by the user is between the sizes of two surveyed projects, CalEEMod conservatively uses the phase duration for the larger project. For instance, if the given project is 7 acres, the program will use the phase duration for the 10-acre project rather than that for the 5-acre project. For large acreage sites, the survey was extrapolated by adding additional phase time equivalent to adding phase time from two acreage ranges in the survey. This occurs for sites larger than 34 acres. In these situations, the user should consider the accuracy of the equipment and phase duration estimations or use site-specific construction schedules and equipment lists. For linear land use types, the default phases and durations are based on the total number of workdays and the user selection of the predominant soil/site type on the **Land Use** screen (refer to Table G-8) (Ramboll 2016). These inputs determine the default construction phase durations.

The date range, workdays per week, and total days are dynamically linked to each other and will influence one another if the user changes these values. Note that while trenching is a phase option, it is not included as a default construction phase. If a project includes trenching, the user must enter site-specific inputs related to trenching on all applicable screens.

4.2 Off-Road Equipment Screen

CalEEMod calculates combustion exhaust emissions from operation of off-road equipment powered by diesel, gasoline, and natural gas. The fuel selection dropdown menu also includes "electric" as an option. Electric-powered equipment does not generate combustion exhaust emissions. When electric-powered equipment is selected, CalEEMod calculates electricity consumption and associated indirect GHG emissions under the **Electricity** screen, as discussed in Section 4.10, *Electricity Screen*. There are also measures that can be implemented that will allow for use of alternatively fueled and electric-powered equipment.

CalEEMod generates default equipment lists based on user inputs in the **Land Use** module. The model relies on the South Coast AQMD construction survey to develop the default equipment lists for non-linear land use types (e.g., Residential) based on total project acreage as calculated from the acreage entered in the **Land Use** module (refer to Table G-9). If the project acreage is in between the acreages in the survey, the next highest acreage tier is used. For large acreage sites, the survey was extrapolated by adding additional phase time equivalent to adding phase time from two acreage ranges in the survey. This occurs for sites larger than 34 acres. In these situations, the user should consider the accuracy of the equipment and phase duration estimations or using site-specific construction schedules and equipment lists.

For linear land use types, a survey of 11 road construction projects (Tetra Tech 2013) is used to inform the default number of equipment and type of equipment per phase, which are based on the land use subtype and maximum area disturbed per day (refer to Table G-10). The maximum area disturbed per day is calculated as the lot acreage divided by the number of workdays in the linear grading phase. The default equipment activity per day is 8 hours per day per equipment. Except for signal boards, the default number of equipment is generated assuming the maximum area disturbed per day is less than or equal to 5 acres. An additional piece of equipment is added for every 5 acres greater than the initial 5-acre threshold. For example, if the maximum area disturbed per day is 6 acres, the amount of equipment for each equipment type would be equal to the baseline number of equipment plus one more piece until the next threshold of 10 acres is surpassed, at which point a second piece of equipment would be added to the total default number of equipment. The default number of signal boards is calculated differently than the other equipment types. The number is based on the linear land use type total size, summed based on the user inputs on the **Land Use** screen, assuming one signal board per half mile.

The calculations associated with this screen include the running exhaust emissions from all fossil-fueled equipment, as well as starting and evaporative emissions from gasoline- and natural gas-fueled equipment. Since the majority of off-road equipment used for construction projects are diesel fueled, CalEEMod assumes all equipment in the default equipment list are diesel-powered. However, the user may override this default and modify the fuel selection. CalEEMod calculates the exhaust emissions based on the CARB (2021a) OFFROAD2017 methodology using the following equation.

$$E_p = \sum_i (EF_i \times Pop_i \times hp_i \times Load_i \times Activity_i)$$

Where:

E = total daily off-road equipment emissions (g/day).

EF = emission factor in grams per horsepower-hour (g/hp-hr) (Table G-11).

Pop = population, or the number of pieces of equipment (number/day).

hp = average horsepower for the off-road equipment (unitless) (Table G-12).

Load = load factor of the off-road equipment (unitless) (Table G-12).

Activity = hours of daily operation of the off-road equipment (hr/day/number).

p = pollutant.

i = equipment type.

The program allows the user to enter the number of pieces of equipment, fuel type, engine tier, horsepower, load factor, and daily hours of operation for each selected equipment type. The following sections describe the development methodology for the off-road equipment emission factors, default average horsepower, and load factor.

4.2.1 Average Horsepower

Average equipment horsepower default data are based on the most populous horsepower bin for each equipment and fuel type combination in OFFROAD2017-ORION (refer to Table G-12). Note that these defaults are different than the OFFROAD2017-ORION horsepower assumptions used in emission factors calculations. This is because the equipment emission factor calculations were performed for each horsepower bin (e.g., 1 to 15, 16 to 25) so that bin-specific emission factor rates could be developed. Defaults for the average equipment horsepower were estimated based on the weighted average horsepower across all horsepower bins for each equipment type. Equipment population is the weighting factor used to combine across horsepower bins.

4.2.2 Load Factor

Load factor is the ratio of the actual average power output to maximum power output of a piece of equipment. Load factors do not vary by horsepower range. Load factors for construction, industrial, and light commercial equipment are based on recent estimates published by CARB (2017b) for all available diesel equipment types and from OFFROAD2011 for diesel equipment types that are not included in the latest published CARB estimates. Load factors for gasoline- and natural gas-powered construction, industrial, and light commercial equipment are from the OFFROAD2007.[4] Refer to Table G-12.

4.3 Off-Road Equipment Emission Factors Screen

Calendar year average emission factors for construction (e.g., excavator, crawler tractors, cranes), industrial (e.g., aerial lifts, forklifts, other material handling equipment), and light commercial (e.g., air compressors, generator sets, pumps) equipment are based on OFFROAD2017-ORION v1.0.1 (CARB 2020b). The model was run in exhaust and evaporative modes on a statewide basis for 41 scenario years (2010–2050). Emission factors were developed for diesel-, gasoline- and natural gas-fueled equipment. Emission factors for each equipment type, horsepower range, and fuel type combination were estimated based on daily emissions and fleet-wide annual energy use (i.e., total horsepower-hours, or hp-hr) reported in model output files. Total energy use was estimated as the product of OFFROAD2017-ORION annual activity, average horsepower and population as shown in following equation.

$$EU_i = Activity_i \times hp_i \times Pop_i$$

Where:

EU = fleetwide annual off-road equipment energy use (hp-hr/year).

$Activity$ = total annual equipment usage (hr/year).

hp = average horsepower for the off-road equipment (unitless).

Pop = total annual population of an off-road equipment (unitless).

i = equipment type.

Emission factors for each piece of equipment and horsepower range were estimated according to the following formula.

$$EF_p = \frac{E_p \times UC_1 \times UC_2}{EU \times LF}$$

Where:

EF = emission factor (g/hp-hr).

E = total exhaust or evaporative emissions (short tons/day).

UC_1 = unit conversion from daily emissions to annual emissions (365 days/year).

UC_2 = unit conversion from short tons to grams (90,7184.740760757 g/short ton).

EU = fleetwide annual off-road equipment energy use (hp-hr/year).

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[4] Load factors are not readily available in the OFFROAD2017-ORION model. Per April 2021 CARB staff input, load factors for gasoline- and natural gas-fueled equipment were obtained from the OFFROAD2007 model.

LF = load factor of the off-road equipment (unitless).

p = pollutant.

Daily exhaust emissions, daily evaporative emissions, and total energy use are outputs from OFFROAD2017-ORION. Load factors were obtained from the latest CARB diesel equipment load factor estimates and OFFROAD2007.

OFFROAD2017-ORION does not estimate CH_4 or N_2O emissions. For each equipment type and fuel type combination, emission factors for CH_4 and N_2O were estimated by multiplying CO_2 emission factors by the mass ratio of CH_4 and N_2O to CO_2 emissions in California's 2000–2018 GHG emission inventory for off-road equipment by fuel type (CARB 2021b).

Note that calendar-year average default emission factors are only available for horsepower ranges reported in OFFROAD2017-ORION. If the user manually inputs an equipment piece with a horsepower that falls outside the OFFROAD2017-ORION horsepower range for that equipment type, a red warning message will appear on the **Off-Road Equipment EF** screen. The user must supply the associated emission factors to enable the quantification of emissions for that equipment type.

Tier specific emission factors for diesel equipment were obtained from CARB's (2017a) Carl Moyer Program Guidelines. Refer to Table G-11 for the calendar year average emission factors and Table G-13 for the tier specific emission factors.

4.4 Dust from Material Movement Screen

Fugitive dust is generated by the various activities during construction, contributing to PM10 and PM2.5 emissions. CalEEMod calculates fugitive dust associated with the site preparation and grading phases from three major activities: grading, bulldozing, and truck loading.[5] Fugitive dust emissions from these activities are calculated using the methodology in USEPA AP-42, as described in the following sections.

4.4.1 Grading Equipment Passes

Fugitive dust emissions from grading equipment passes are estimated using the methodology described in Section 11.9 of USEPA's AP-42 (USEPA 1998b). Section 11.9 provides guidance to estimate the emission factor of PM10 by applying a scaling factor to PM15. Similarly, the emission factor of PM2.5 is scaled from that of total suspended particulates (TSP). The following presents the equations used to calculate the emission factors for PM15 and TSP and the scaling factors for PM10 and PM2.5.

$$EF_{PM15} = 0.051 \times (S)^{2.0}, \text{ and } EF_{PM10} = EF_{PM15} \times F_{PM10}$$

$$EF_{TSP} = 0.04 \times (S)^{2.5}, \text{ and } EF_{PM2.5} = EF_{TSP} \times F_{PM2.5}$$

Where:

EF = emission factor (lb/VMT).

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[5] While defaults are only available the site preparation and grading phases, the user can model dust emissions from material movement under any phase in the construction schedule by clicking "Add Phase." The user must define the total acres graded for all non-default phases.

S = mean vehicle speed (mph). The AP-42 default value is 7.1 mph.

$F_{PM2.5}$ = PM2.5 scaling factor. The AP-42 default value is 0.031.

F_{PM10} = PM10 scaling factor. The AP-42 default value is 0.6.

Grading dust emissions are calculated by multiplying the emission factors with the total VMT for the grading equipment (i.e., grader). VMT is estimated based on the dimensions of the grading area and the blade width of the grading equipment.

$$E_p = EF_p \times VMT\text{, and}$$

$$VMT = As/Wb \times UC_1 \div UC_2$$

Where:

E = emissions (lb/day).

EF = emission factor (lb/VMT).

VMT = vehicle miles traveled (mile).

As = the acreage of the grading site (acre/day).

Wb = Blade width of the grading equipment. The program uses a default blade width of 12 feet based on Caterpillar’s 140 Motor Grader (Caterpillar 2021).

UC_1 = unit conversion from acre to square feet (43,560 sqft/acre).

UC_2 = unit conversion from feet to miles (5,280 feet/mile).

p = pollutant (PM10 or PM2.5).

The dimensions (e.g., length and width) of the grading site have no impact on the calculation, only the total area to be graded. Multiple passes with equipment may be required to properly grade a piece of land. The acres value is based on the equipment list and the number of days specified for the grading or site preparation phase according to the anticipated maximum number of acres a given piece of equipment can pass over in an 8-hour workday, as determined by South Coast AQMD in consultation with building estimator references (refer to Table G-14).

4.4.2 Bulldozing

Similar to the grading equipment passes emission estimation, the bulldozing emission factors for fugitive dust are scaled from the emission factors for PM15 and TSP. Based on AP-42 Section 11.9, the dust emission factors for bulldozing are calculated using the following equations (USEPA 1998b).

$$EF_{TSP} = \frac{C_{TSP} \times s^{1.2}}{M^{1.3}}\text{, and } EF_{PM2.5} = EF_{TSP} \times F_{PM2.5}$$

$$EF_{PM15} = \frac{C_{PM15} \times s^{1.5}}{M^{1.4}}\text{, and } EF_{PM10} = EF_{PM15} \times F_{PM10}$$

Where:

EF = emission factor (lb/hr).

C = arbitrary coefficient used by AP-42.

M = material moisture content (%).

s = material silt content (%).

F = scaling factor.

C, M, s, and F vary depending on the bulldozed material. Table C-1 summarizes the constants for overburden presented in AP-42 (USEPA 1998b:Tables 11.9-1 and 11.9-3).[6]

Table C-1. Bulldozing Fugitive Emission Factors

Constant	Overburden
C_{TSP}	5.7
C_{PM15}	1.0
M	7.9%
s	6.9%
F_{PM10}	0.75
$F_{PM2.5}$	0.105

The program uses the constants associated with overburden as defaults for the calculation of bulldozing dust emissions since overburden more closely models the bulldozed materials during land development construction. The dust emissions are calculated by multiplying the emission factor with the hours of operation for the dozers listed in the equipment list using the following formula.

$$E_p = EF_p \times Hr$$

Where:

E = emissions (lb/day).

EF = emission factor (lb/hr).

Hr = hours of operation (hr/day).

p = pollutant (PM10 or PM2.5).

4.4.3 Truck Loading

Processes such as a truck dumping earthen materials on a pile or loading soil from a pile to a truck with a front-end loader cause fugitive dust emissions. CalEEMod calculates these emissions using the methodology described in Section 13.2.4 of USEPA AP-42 (USEPA 2006a). The emission factor is based on the material moisture content and mean wind speed and is calculated using the following equation.

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[6] *Overburden* is the layer of earth located between the topsoil and the coal seam.

$$EF_p = k \times (0.0032) \times \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$$

Where:

EF = emission factor (lb/short ton).

K = particle size multiplier. The AP-42 default value for PM10 is 0.35 and that for PM2.5 is 0.053.

U = mean wind speed. The program selects wind speed based on the value listed on the **Project Detail** screen. It has been converted internally to miles per hour.

M = material moisture content (percent). The moisture contents of different materials are listed in AP-42 (USEPA 2006a:Table 13.2.4-1). The program uses the moisture content of cover (12%) as default.

p = pollutant (PM10 or PM2.5).

Fugitive dust emissions are calculated by multiplying the emission factor with the throughput of loaded and unloaded material that is entered by the user (i.e., material imported and exported).

$$E_p = EF_p \times TP$$

Where:

E = emissions (lb/day).

EF = emission factor (lb/short ton).

TP = throughput of loaded and unloaded materials (short ton/day). Refer to Appendix D, *Technical Source Documentation for Emissions Calculations,* for suggested material movement quantities by project land use type and size.

p = pollutant (PM10 or PM2.5).

CalEEMod assumes 1.2641662 short tons per cubic yard based on a bulk density of 1.5 grams per cubic centimeter. Typical soil densities range from about 1.25 to about 1.6, and 1.5 is the approximate density of a silty loam soil, which is relatively common in most other parts of the state. The density reported above does not account for watering to suppress dust, it only accounts for natural moisture. See Section 4.4.4, *Emissions Control*, for instructions on including dust control in the emissions analysis.

4.4.4 Emissions Control

If applicable, the user may select the “Water Exposed Area” toggle to account for dust control as part of the project design. Default reduction efficacies are available for watering exposed surfaces at frequencies of 2 or 3 times per 8-hour workday, based on published literature (Countess Environmental 2006:Table 3-7). The twice daily efficacy assumes watering every 3.2 hours and achieves a 61 percent reduction in fugitive dust emissions from grading equipment passes, bulldozing, and truck loading. The three times daily efficacy assumes watering every 2.1 hours and achieves a 74 percent reduction in fugitive dust emissions from these sources. The user may also define their own watering frequency and reduction factors by selecting “Other” from the dropdown menu.[7] If the “Water Exposed Area” toggle is selected, the reduction efficacies will be applied to the calculation of unmitigated fugitive dust.

4.5 Demolition Screen

The program calculates demolition dust emissions using the methodology described in the report prepared for USEPA by the Midwest Research Institute (MRI) (1988). The three primary operations that generate dust emission during the demolition phase are (1) mechanical or explosive dismemberment, (2) debris loading, and (3) truck travel over paved and unpaved roads. Emissions from on-road truck travel are included in the **Trips and VMT** screen (see Section 4.6, *Trips and VMT Screen*). This section describes the quantification method for mechanical or explosive dismemberment and debris loading. CalEEMod adds the emissions from these sources to calculate total fugitive dust emissions from demolition activities.[8]

4.5.1 Mechanical or Explosive Dismemberment

Based on the MRI report, there are no AP-42 emission factor data available for mechanical or explosive dismemberment. Thus, the emission factor for dismemberment and collapse of a structure is calculated using the following AP-42 equation for batch drop operations (USEPA 2006a).

$$EF_D = k \times (0.0032) \times \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$$

Where:

EF_D = dismemberment emission factor (lb/short ton of debris).

k = particle size multiplier. The AP-42 default value for PM_{10} is 0.35 and that for $PM_{2.5}$ is 0.053.

U = mean wind speed. The program selects the default mean wind speed based on the wind speed (m/s) provided on the **Project Detail** screen.

M = material moisture content. The program uses 2% as the default based on the MRI report.

p = pollutant (PM10 or PM2.5).

The dust emissions are calculated by multiplying the above emission factors with the total weight of building waste using the following equation.

$$E_{D \cdot p} = EF_{D \cdot p} \times W$$

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[7] Local air districts may have suggestions for reduction efficacies in their CEQA guidelines.

[8] The user can model dust emissions from demolition under any phase in the construction schedule by clicking “Add Phase.” They user must define the square footage of demolished area or short tons of building debris.

Where:

E_D = dismemberment emissions (lb/day).

EF_D = dismemberment emission factor (lb/short ton of debris).

W = building waste (short ton of debris/day).

p = pollutant (PM10 or PM2.5).

If the total building waste weight is not known, the program will estimate the tonnage using the *building waste tonnage – structural floor space* relationship determined from a 1976 analysis by Murphy and Chatterjee of the demolition of 12 commercial brick, concrete, and steel buildings. The following data are cited directly from the MRI report:

1 sqft floor space = 10 cubic feet original building volume,
1 cubic foot building volume = 0.25 cubic foot waste volume,
1 cubic yard building waste = 0.5 short ton weight; therefore,
1 sqft represents 0.046 short ton of waste material.

The total building waste is then calculated using the following equation:

$$E_{D \cdot p} = EF_{D \cdot p} \times SF \times UC_1$$

Where:

E_D = dismemberment emissions (lb/day).

EF_D = dismemberment emission factor (lb/short ton of debris).

SF = building square footage (sqft/day).

UC_1 = unit conversion from square feet to short ton (0.046 short ton/sqft).

p = pollutant (PM10 or PM2.5).

4.5.2 Debris Loading

Debris loading emission factors for fugitive dust are scaled from the emission factor for TSP according to the following equation.

$$EF_{L \cdot p} = k \times EF_{L\text{-}TSP}$$

Where:

EF_L = loading dust emission factor (lb/short ton).

k = particle size multiplier. The AP-42 default values are 0.35 for PM10 and 0.053 for PM2.5.

$EF_{L\text{-}TSP}$ = loading TSP emission factor (lb/short ton). The default value is 0.058 lb/short ton, the average of TSP factors (i.e., 0.053 and 0.063 lb/short ton) measured from two tests of the filling of trucks with crushed limestone using a front-end loader (Midwest Research Institute 1988:28).

p = pollutant (PM10 or PM2.5).

PM10 and PM2.5 dust emissions from debris loading are then calculated following the same methodology as used for mechanical or explosive dismemberment.

$$E_{L\cdot p} = EF_{L\cdot p} \times SF \times UC_1$$

Where:

E_L = loading emissions (lb/day).

EF_L = loading emission factor (lb/short ton).

SF = building square footage (sqft/day).

UC_1 = unit conversion from square feet to short ton (0.046 short ton/sqft).

p = pollutant (PM10 or PM2.5).

4.5.3 Emissions Control

If applicable, the user may select the “Water Demolished Area” toggle to account for dust control as part of the project design. Default reduction efficacies are available for watering during demolition at a frequency of 2 times per 8-hour workday, based on published literature (Countess Environmental 2006:Table 3-7). The twice daily efficacy assumes watering every 4 hours and achieves a 36 percent reduction in fugitive dust emissions from demolition. The user may also define their own watering frequency and reduction factors by selecting “Other” from the dropdown menu.[9] If the “Water Demolished Area” toggle is selected, the reduction efficacies will be applied to the calculation of unmitigated fugitive dust.

4.6 Trips and VMT Screen

The number of workers, vendor, hauling, and onsite truck trips and associated VMT are used to determine both the exhaust and mechanical (i.e., tirewear and brakewear) emissions associated with on-road vehicle use, as well as fugitive dust emissions from travel over paved and unpaved roads. CalEEMod defines these trip types as follows:

- *Worker*: Trips made by employees commuting from an offsite origin to the construction site. Defaults for worker trip numbers and lengths are automatically generated for all construction phases and land use types based on prior user inputs.
- *Vendor*: Trips made by water or cement trucks traveling from an offsite origin to the project site. Defaults for vendor trip numbers and lengths are automatically generated for all construction phases identified for linear land use projects. Defaults for vendor trip numbers and lengths for land use development projects are only available for the building construction phase.
- *Hauling*: Trips made by heavy trucks traveling from an offsite origin to the project site. Defaults for hauling trip numbers are automatically generated for all construction phases in which the user has defined a material quantity in the **Demolition** or **Dust from Material Movement** screens. The hauling trip length default is set at 20 miles per one-way trip.
- *Onsite Truck*: Trips made by heavy trucks traveling within the construction property boundary. There are no trip rate or length defaults for onsite trucks.

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[9] Local air districts may have suggestions for reduction efficacies in their CEQA guidelines.

This section provides the sources consulted to develop default values for vehicle trip rates and lengths and provides the quantification methodology for the estimation of vehicle emissions (exhaust and mechanical). See Section 4.7, *On-Road Fugitive Dust Screen*, for the road dust quantification method.

4.6.1 Default Values for Vehicle Trip Rate

Worker trips for all construction phases except building construction and architectural coating is based on 1.25 workers per equipment in that phase resulting in one roundtrip per worker. For building construction workers, the trip number is estimated using the trip generation rate from a survey conducted by the Sacramento Metropolitan Air Quality Management District. This has been reanalyzed and results in slightly different numbers than used by other programs and that was previously reported in some agency documents. The analysis and data supporting these values can be found in Appendix D, *Technical Source Documentation for Emissions Calculations*. The land types selected for the project are grouped into four categories presented in Table C-2, which also presents the associated Sacramento Metropolitan Air Quality Management District trip generation rates.

Table C-2. Building Construction Worker and Vendor Trip Rates

Land Use Subtype	Rate Metric	Worker Trip Rate	Vendor Trip Rate
Single-Family	Daily trips per DU	0.36	0.1069
Multi-Family	Daily trips per DU	0.72	0.1069
Commercial/Retail	Daily trips per 1000 square feet	0.32	0.1639
Office/Industrial	Daily trips per 1000 square feet	0.42	0.1639

Source: South Coast AQMD's analysis of the Sacramento Metropolitan Air Quality Management District's Building Construction Worker and Vendor trip rates found in Appendix D, *Technical Source Documentation for Emissions Calculations*.
DU = dwelling unit

Architectural coating worker trips are 20 percent of building construction phase trips. Defaults for vendor trips for land use development projects are only available for building construction and are based on the land uses and trip rate indicated in Table C-2. The user must provide vendor trips rates for all other phases for land use development projects requiring this type of vehicle trip. Appendix D, *Technical Source Documentation for Emissions Calculations,* includes suggested vendor trip rates for construction phases where defaults are not currently programmed. For linear land use types, defaults for the number of one-way vendor trips per day are available for all construction phases. The vendor trip rate accounts for water trucks but no other types of vendors (e.g., cement trucks). If the linear land use construction requires other types of vendor trips, the user will need to add those trips to the defaults quantified for water trucks. The derivation of the default total water truck trips per linear phase is a three-step process.

1. The number of one-way trips per water truck is estimated to be 10 per day, based on average trip data output from EMFAC2017 for T7 single construction trucks (Ramboll 2018).
2. The number of trucks per day for the "Linear, Grubbing & Land Clearing" and "Linear, Grading & Excavation" phases are based on the maximum area disturbed per day, divided by 5. For the "Linear, Drainage, Utilities, & Sub-Grade" and "Linear, Paving" phases, the maximum area disturbed per day is divided by 10.

3. The number of one-way trips per water truck is multiplied by the number of trucks per day to calculate the total water truck trips per day per phase.

Hauling trips are based on the amount of material that is demolished (as defined in the **Demolition** screen) or imported or exported (as defined in the **Dust from Material Movement** screen) assuming a truck can handle 16 cubic yards of material. For phased trips, the truck is assumed to be full both ways. For non-phased trips, the truck is assumed to be empty one direction and thus results in more haul trips calculated. The user must provide hauling trips rates for all activities not associated with demolition or material movement, as applicable.

There are no trip rate defaults for onsite trucks. The user must enter site-specific assumptions when a project includes onsite truck trips. Refer to Appendix D, *Technical Source Documentation for Emissions Calculations,* for suggested onsite trip rates and lengths.

4.6.2 Default Values for Vehicle Trip Lengths

As described further in Section 5.1.1.1, *Default Vehicle Trips and VMT*, CalEEMod includes default trip length estimates from the 2015 California Statewide Travel Demand Model (CSTDM) and regional travel demand models from local metropolitan planning organizations (MPO) or Regional Transportation Planning Agencies (RTPA), where available. If MPO/RTPA data are available for the project location, the user may select either data source by clicking the appropriate toggle.

Both the CSTDM and MPO/RTPA databases include trip length information for home-work (H-W) and work-other (W-O) trips. A H-W trip represents trips traveling in either direction between home and work locations and is used to define construction worker trips. A W-O trip is made by an employee traveling in either direction between a work location and all other locations that are not home and is used to define construction vendor trips.

If the CSTDM is selected, the default trip lengths for workers and vendors are based on the statewide data for H-W and W-O trips, respectively, aggregated to the user-selected analysis level defined on the **Project Detail** screen (refer to Table G-15). If MPO/RTPA is selected, the trip length for workers and vendors are based on the local data for H-W and W-O trips, respectively, aggregated to the MPO/RTPA jurisdictional boundary (refer to Table G-16).

The hauling trip length default is set at 20 miles. There are no trip length defaults for onsite trucks.

4.6.3 Emissions Quantification

On-road vehicles generate combustion exhaust emissions (running and evaporative) and dust emissions from tirewear and brakewear (i.e., mechanical) (dust emissions from vehicle travel over paved and unpaved roads are discussed in Section 4.7, *On-Road Fugitive Dust Screen*). These emissions are based on the vehicle trips rates and lengths along with emission factors from EMFAC2021 (California Air Resources Board 2021c). The detailed methodology for converting EMFAC2021 emission rates into CalEEMod vehicle emission factors is provided in Section 5.1.3.1, *Vehicle Emission Factors from EMFAC2021*. This section provides the quantification methodology for the estimation of combustion exhaust and mechanically generated dust emissions from construction vehicle trips. Because the vehicle fleet mix influences the intensity of emissions, defaults for defining the vehicle mix are also described.

4.6.4 Vehicle Fleet Mix

The user can select the type of vehicle mix for each of the four construction trip types (e.g., worker). CalEEMod assumes that construction worker trips are made by a fleet consisting of 25 percent light-duty auto (or passenger car), 50 percent light-duty truck type 1 (LDT1), and 25 percent light-duty truck type 2 (LDT2). This is an assumed fleet mix based on field observations. The user may override this default to use the EMFAC fleet mix, which is the total mix of all vehicles for the analysis level provided by EMFAC2021.

CalEEMod assumes vendor trips are made by a fleet consisting of 50 percent medium trucks (MHDT) and 50 percent heavy trucks (HHDT). CalEEMod assumes hauling and onsite truck trips are made by a fleet consisting of 100 percent HHDT. The user may override these defaults to use the EMFAC fleet mix, MHDT/HHDT mix, all MHDT, or all HHDT.

The equivalent test weight (ETW) from EMFAC2021 for each type of vehicle is presented in Table C-3 (CARB 2021d).

Table C-3. Gross Vehicle Weights

Vehicle Type	ETW (lb)
LDA	All
LDT1	<= 3,750
LDT2	3,751 – 5,750
MHDT	14,001 – 33,000
HHDT	33,000 – 60,000

4.6.5 Exhaust Emissions (Running and Evaporative)

EMFAC2021 emission factors for each construction vehicle fleet mix are based on aggregated model year and vehicle speeds for the user-selected analysis level defined on the **Project Detail** screen. The emission factor database includes emission factors for all calendar years (2010–2050) and seasons (summer, winter). CalEEMod identifies the appropriate calendar year and seasonal emission factors based on the start and end dates of the construction phases. Running exhaust emission factors are presented in units of grams per mile (g/mile) and evaporative emission factors are presented in units of grams per trip (g/trip). While combustion results in running exhaust emissions of all criteria pollutants and GHGs, evaporative emissions are only emitted as TOG and ROG. See Section 5.1.3.1, *Vehicle Emission Factors from EMFAC2021*, for additional information on the sources and methods used to develop the running and evaporative emission factors.

Emissions from construction vehicle trips are calculated using the following equation.

$$E_p = ((EEF_{m,s} \times Trips) + ((REF_{m,s} \times Trips \times Length))$$

Where:

E = combustion emissions (g/day).

EEF = evaporative emission factor (g/trip) (ROG and TOG only).

REF = running exhaust emission factor (g/mile).

Trips = vehicle trips (trips/day).

Length = vehicle trip length (miles/trip).

m = vehicle fleet mix.

s = season. CalEEMod applies winter emission factors to vehicle trips made during phases that occur between October through March, and summer emission factors to vehicle trips made during phases that occur between April through September.

p = pollutant (PM10 or PM2.5).

4.6.6 Mechanical Emissions (Tirewear and Brakewear)

As vehicles are driven, PM10 and PM2.5 are generated from degradation of brakes and tires. These emissions are calculated using the following equation. Note that seasonality (winter, summer) does not influence the intensity of brakewear or tirewear emissions.

$$E_p = (BWEF + TWEF)_m \times (Trips \times Length)$$

Where:

E = dust emissions (g/day).

BWEF = brakewear emission factor (g/mile).

TWEF = tirewear emission factor (g/mile).

Trips = vehicle trips (trips/day).

Length = vehicle trip length (miles/trip).

m = vehicle fleet mix.

p = pollutant (PM10 or PM2.5).

4.7 On-Road Fugitive Dust Screen

CalEEMod calculates fugitive dust from travel of construction vehicles on paved and unpaved roads consistent with the method discussed in Section 5.1.4, *Road Dust Screen*. All worker, vendor, and hauling trips are assumed to occur on public roadways (i.e., not within the project construction boundary). The percentage of vehicle miles travel on paved roadways is based on the user-selected analysis level defined on the **Project Detail** screen. The local air districts were surveyed to request that they provide percentages for their corresponding location types (i.e., air basin, air district, and county). The statewide default assumption of 100 percent was applied to the smaller location types unless the local air district specified alternative percentages. All onsite trucks trips are assumed to occur within the project construction boundary and therefore exclusively on unpaved roads. Defaults for roadway characteristics (e.g., road silt loading content) and vehicle characteristics (e.g., average vehicle weight) are the same as described in Section 5.1.4, *Road Dust Screen*.

4.7.1 Emissions Control

If applicable, the user may select the “Control Strategy” toggle to account for dust control as part of the project design. The following four control strategies are available.

- Water unpaved roads twice daily.
- Apply dust suppressants to unpaved roads.

- Limit vehicle speeds on unpaved roads to 25 mph.
- Sweep paved roads once per month.

The first three strategies influence the intensity of dust generation from vehicle travel on unpaved roads within the project construction boundary. Watering and application of dust suppressants are mutually exclusive—that is, the user may select watering or dust suppressants, but not both. The last strategy influences the intensity of dust generation from vehicle travel on paved roads within the project construction boundary. This strategy is only applicable if the percentage of paved onsite truck travel is greater than 0.

Default reduction efficacies for the four strategies are based on published literature (Countess Environmental 2006:Tables 3-7, 6-6, and 5-5). If the “Control Strategy” toggle is selected, the reduction efficacies will be applied to the calculation of unmitigated fugitive dust.

4.8 Architectural Coatings Screen

VOC off-gassing emissions result from evaporation of solvents contained in surface coatings. The program calculates the VOC evaporative emissions from application of residential and non-residential surface coatings. The architectural coating emission factor is based on the VOC content of the surface coatings and is calculated estimated using the following equation.

$$EF = C_{VOC} \times UC_1 \times UC_2 \div S$$

Where:

EF = architectural coating emission factor (lb VOC/sqft).

C_{VOC} = VOC content (g/L). This varies by location and year based on VOC content data provided by California air districts. If data were not available from a local air district, CalEEMod assumes CARB’s statewide limits (Table G-17).

UC_1 = unit conversion from grams to lb (0.00220462262 lb/g).

UC_2 = unit conversion from gallons (gal) to liters (L) (3.78541 L/gal).

S = sqft coated per gal (180 sqft/gal).

Architectural coating emissions are calculated using the following equation.

$$E = EF \times F \times A_{paint}$$

Where:

E = architectural coating emissions (lb VOC/day).

EF = architectural coating emission factor (lb VOC/sqft).

F = fraction of surface area. For all land use types except Parking, the default values based on South Coast AQMD methods used in their coating rules are 75% for the interior surfaces and 25% for the exterior shell. The fractions for the Parking land use type are 90% for interior surfaces and 10% for the exterior shell.

A_{paint} = building surface area painted (sqft).

The program assumes the total surface for painting as follows.

- 2.7 times the building square footage for residential land uses.
- 2.0 times the building square footage for non-residential land uses, with the following exceptions.
    - 2.0 times the recreational building square footage for City Park, Golf Course, and Recreational Swimming Pool land use subtypes.[10]
    - 0.05 times the lot acreage (converted to square feet) for the Parking land use type.

All land use information provided by a metric other than square footage (e.g., gasoline station pumps) will be converted to square footage using the default conversions or user defined equivalence.

CalEEMod also calculates VOC emissions from the painting of stripes, handicap symbols, directional arrows and car space descriptions for the Parking land use type. See Appendix D, *Technical Source Documentation for Emissions Calculations*, for the studies conducted to determine a default percent of parking lot square footage that is painted. The equation for striping emission is the same as that for E_{AC} above, but A_{paint} is as follows.

$$A_{paint} = A_{PL} \times P$$

Where:

A_{PL} = parking lot area (sqft).

P = percent of parking lot area that is painted (6%).

The VOC content limit for parking lot area is either provided by local air districts or based on the exterior coating VOC limit of the region where the project is located.

4.9 Paved Area Screen

CalEEMod estimates VOC off-gassing emissions associated with paving of asphalt surfaces using the following equation.

$$E = EF \times A \times P$$

Where:

E = paving emissions (lb VOC/day).

EF = paving emission factor (lb VOC/acre). The default emission factor is 2.62 lb/acre (Sacramento Metropolitan Air Quality Management District 1994).

A = area paved (acre).

CalEEMod provides default inputs for area paved for the single-family housing land use subtype and all linear and parking land use subtypes. Defaults for single-family housing

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[10] The factors 2.7 and 2 are based on page A9-124 of South Coast AQMD’s 1993 *CEQA Air Quality Handbook*.

are generated based on the unit amount defined in the **Land Use** module, assuming 480 sqft of paved driveway space per DU. The area paved for linear and parking land use subtypes is equal to the lot acreage defined in the **Land Use** module. CalEEMod assumes 0 paved area for all other land use types. The user may override this value if their project includes additional paving.

P = percent of area that is paved with asphalt (%).

Evaporative VOC emissions are only generated by asphalt paving. CalEEMod defaults to 100 percent asphalt paving for all parking lot (except for "other non-asphalt surfaces") and linear land use subtypes. Paving for all other land use types is assumed non-asphalt (e.g., concrete) and the default percent is set to 0.

4.10 Electricity Screen

CalEEMod calculates GHG emissions from the consumption of electricity during construction according to the following equation.

$$E_p = EF_p \times EC \times UC_1$$

Where:

E = electricity emissions (lb/yr).

EF = utility emission factor (lb/MWh) (Table G-3).

EC = annual construction electricity consumption (kilowatt-hours per year [kWh/yr]).

UC_1 = unit conversion from kWh to MWh (0.001 MWh/kWh).

p = pollutant (CO_2, CH_4, and N_2O).

CalEEMod displays the construction years for the project based on the construction schedule defined in the **Construction Phases** screen. CalEEMod only calculates electricity consumption if the user identifies electric-powered construction equipment in the **Off-Road Equipment** screen. Electricity consumption for off-road equipment is estimated according to the following equation.

$$EC = Activity_i \times Pop_i \times (hp_i \times UC) \times Load_i \times D$$

Where:

EC = annual electricity consumption (kWh/yr).

$Activity$ = hours of daily operation of the off-road equipment (hr/day/number).

Pop = population, or the number of pieces of equipment (number/day).

hp = average horsepower for the off-road equipment (unitless) (Table G-12).

UC = unit conversion from horsepower to kW (0.745701 kW/hp).

$Load$ = load factor of the off-road equipment (unitless) (Table G-12).

D = days per year of equipment operation, as defined by the phase duration (day/yr).

i = off-road equipment type.

CalEEMod does not estimate electricity consumption for any source other than user-defined electric-powered equipment (e.g., mobile offices, electric haul trucks). The user must enter site-specific assumptions when a project includes non-equipment sources of electricity consumption. Note that if a phase requires electricity for both equipment and non-equipment sources, the user would need to add their non-equipment electricity estimate to the CalEEMod generated default for equipment electricity consumption.

As discussed in Section 2.2, *Utility Information Screen*, CalEEMod includes carbon intensities for several electric utilities throughout California, as well as the carbon intensity for the statewide grid average. Electricity emissions can be quantified using the latest year with reported data, which is 2019. Alternatively, the user may elect to use forecasted future year carbon intensities that reflect implementation of SB 100. If the forecasted factors toggle is selected, CalEEMod will use the forecasted carbon intensities applicable to each construction year.

4.11 Maximum Daily and Annual Construction Emissions

Since construction phases may or may not overlap in time, the maximum daily construction emissions will not necessarily be the sum of all possible daily emissions. CalEEMod calculates daily emissions for each construction phase. The program will then add together the daily emissions for each construction phase that overlaps in time. The model also accounts for seasonality and calculates the highest daily emissions that would occur during the winter (October through March) and summer (April through September) seasons. For example, consider a project with the phases and schedule shown in Table C-4.

Table C-4. Example Schedule

Phase	Start Date	End Date	Days	Days/Week
Demolition	1/1/2022	1/30/2022	20	5
Site Preparation	2/1/2022	3/15/2022	31	5
Grading	3/1/2022	3/31/2022	23	5
Building Construction	4/1/2022	10/30/2023	412	5
Architectural Coatings	9/1/2023	10/30/2023	42	5
Paving	10/15/2023	10/30/2023	11	5

As shown in Table C-4, the site preparation and grading phases would occur concurrently between 3/1/2022 and 3/15/2022. Likewise, the building construction and architectural coatings phases would occur concurrently between 9/1/2023 and 10/30/2023. The paving phase would overlap with both building construction and architectural coatings between 10/15/2023 and 10/30/2023. During these periods of overlapping construction activity, CalEEMod adds daily emissions among the phases to calculate combined daily emissions. The program will then select the highest emissions among the individual phases and combined overlapping periods to report as the daily summer and winter maximums.

Table C-5 illustrates the calculation of maximum daily NO_x emissions for the example project. As shown in the table, NO_x emissions for the overlapping winter period in 2022 are 37 lb per day. This amount is greater than the emissions that would be independently generated by either the site preparation (20 lb) or grading (17 lb) phases and would therefore be reported for the maximum daily winter output in 2022. There would be no phase overlap in the construction schedule between 4/1/2022 and 9/1/2023. Emissions from the building construction phase (36 lb) would be reported as the maximum daily summer output in 2022. For the overlapping summer period in

2023, the highest NO_x emissions are 38 lb, which occurs between 9/1/2023 and 9/30/2023. This value exceeds the emissions estimate for the building construction phase that would occur independently earlier in the 2023 summer season. Accordingly, 38 lb per day would be reported in the CalEEMod output as the maximum daily summer NO_x emissions in 2023. For the overlapping winter period in 2023, the highest NO_x emissions are 42 lb. These emissions would be reported as the daily winter maximum for 2023. The consideration of seasonality in the presentation of summer and winter outputs is new to version 2022.1 and can result in considerable differences in maximum daily summer and winter results.

Table C-5. Example Maximum Daily Nitrogen Oxides Calculation

Phase	**Daily Nitrogen Oxides Emissions (lb)**	**Overlapping Periods**		
		3/1/2022 to 3/15/2022	**9/1/2023 to 10/30/2023**	**10/15/2023 to 10/30/2023**
	Year and Season	*2022 Winter*	*2023 Summer* *2023 Winter*	*2023 Winter*
Demolition	10	-	-	-
Site Preparation	20	20	-	-
Grading	17	17	-	-
Building Construction	36	-	36	36
Architectural Coatings	2	-	2	2
Paving	4	-	-	4
Total Emissions	-	37	38	42
Max Daily Emissions (lb) for CalEEMod Output				
2022 Winter [a]	37			
2022 Summer [b]	36			
2023 Winter [c]	42			
2023 Summer [d]	38			

Notes:

[a] The 2022 winter seasons are from 1/1/2022 to 3/30/2022 and 10/1/2022 to 12/31/2022. The highest emissions that occur during these dates are from concurrent site preparation and grading (3/1/2022 to 3/15/2022). The combined emissions (37 lb) from these phases exceed the emissions that would be independently generated by any other phase during the winter 2022 season.

[b] The 2022 summer season is from 4/1/2022 to 9/30/2022. Only the building construction phase would occur during this time, and therefore would be reported as the summer 2022 maximum.

[c] The 2023 winter seasons are from 1/1/2023 to 3/30/2023 and 10/1/2023 to 12/31/2023. The highest emissions that occur during these dates are from concurrent building construction, architectural coatings, and paving (10/15/2023 to 10/30/2023). The combined emissions (42 lb) from these phases exceed the emissions that would be independently generated by any other phase (or other overlapping phase combinations) during the winter 2023 season.

[d] The 2023 summer season is from 4/1/2023 to 9/30/2023. The highest emissions that occur during these dates are from concurrent building construction and architectural coatings (9/1/2023 to 9/30/2023). The combined emissions (38 lb) from these phases exceed the emissions that would be independently generated by any other phase during the summer 2023 season.

Annual construction emissions are calculated based on the daily emissions for each construction phase and the construction schedule defined in the **Construction Phases** screen. CalEEMod assigns all emissions for a phase to a single year if the start and end dates both occur in that year. For phases that span multiple years, CalEEMod calculates the number of days in each year the phase would occur based on the phase start and end dates and working days per week. CalEEMod then multiplies the daily phase emissions by the number of days the phase would occur in each year. Table C-6 illustrates the calculation of annual emissions for the example project.

Table C-6. Example Annual Nitrogen Oxides Calculation

Phase	Daily Nitrogen Oxides Emissions (lb)	2022			2023		
		lb/day	day/year	lb/year	lb/day	day/year	lb/year
Demolition	10	10	20	200	0	0	0
Site Preparation	20	20	31	620	0	0	0
Grading	17	17	23	391	0	0	0
Building Construction	36	36	196	7,056	36	216	7,776
Architectural Coatings	2	0	0	0	2	42	84
Paving	4	0	0	0	4	11	44
Total Emissions (lb)	**-**	**-**	**-**	**8,267**	**-**	**-**	**7,904**
Total Emissions (short tons) for CalEEMod Output	**-**	**-**	**-**	**4.13**	**-**	**-**	**3.95**

5 Operations Module

The **Operations** module is used to calculate the emissions associated with operation of a land use development (i.e., non-linear) project. The operational phase of a project can have several different types of sources that contribute to emissions. The sources quantified by CalEEMod are mobile, area, energy, water and wastewater, solid waste, refrigerants, off-road equipment, and stationary. Each of these source types is discussed in more detail in the subsequent sections.

5.1 Mobile Sources Submodule

On-road operational mobile source emissions are generated by resident, worker, customer, and delivery vehicles visiting the land use subtypes of a project. The emission processes associated with on-road mobile sources includes running, starting, idling, evaporative, and mechanical (i.e., brakewear, tirewear, and road dust). Running and mechanical emissions depend on VMT. All other emissions depend on the number of vehicle trips. Emissions from these processes are quantified based on user inputs and defaults in the **Vehicle Data**, **Fleet Mix**, **Vehicle EF**, and **Road Dust** screens.

The methods and assumptions used by the program to quantify mobile source emissions are described in the following sections. Section 5.1.1.1, *Default Vehicle Trips and VMT*, explains how CalEEMod generates default vehicle trip and VMT forecasts for use if project-specific data are not available. Section 5.1.3, *Vehicle Emission Factors Screen*, describes the methodology for converting EMFAC2021 emissions rates to CalEEMod mobile source emission factors. This section also provides the equations and variables used to develop emission factors for HFC. Section 5.1.4, *Road Dust Screen,* provides the equations and variables used to develop emission factors for road dust. Section 5.1.5, *Mobile Source Emissions Quantification,* provides the final equations for quantifying mobile source emissions.

5.1.1 Vehicle Data Screen

CalEEMod can generate default assumptions for vehicle trips and VMT based on user inputs in the **Project Details** and **Land Use** screens. Alternatively, the user may provide project-specific trip and VMT inputs from a traffic study or other source by clicking “Enter Trips and VMT Manually” in the **Vehicle Data** screen. The following sections define the methodology used by CalEEMod to generate default vehicle trips and VMT.

5.1.1.1 Default Vehicle Trips and VMT

5.1.1.1.1 General Methodology

The specific type of trip and VMT forecast by CalEEMod is referred to as “project generated trips and VMT” and it is inclusive of all vehicle types (i.e., passenger and commercial vehicles) and trip purposes for either an “average day” or “peak day.” The day type is dependent on the selected emissions report (i.e., annual or daily). The simplified VMT calculation multiplies the vehicle trips generated from the project’s land use subtypes by vehicle trip lengths, as shown in the following equation.

$$\text{VMT} = \text{Vehicle Trips} \times \text{Vehicle Trip Lengths}$$

This equation calculates the total VMT generated from the project’s land use subtypes but does not capture the “project’s effect on VMT.” Land use projects have the potential to influence existing VMT generated by neighboring land uses and from vehicle trips already traveling on the network under baseline conditions.[11] A more complete analysis of VMT would provide forecasts of both project-generated VMT and the project’s effect on VMT. Travel demand models can produce both metric forms, while CalEEMod is limited to project-generated forecasts.

5.1.1.1.2 Data Fields and Sources

CalEEMod is populated with the following data fields used to estimate vehicle trips and VMT.

- *Trip rate:* Weekday, Saturday, and Sunday vehicle trip rates primarily from *Trip Generation Manual, 10th Edition* (ITE 2017a). A few rates are from the 9th Edition (ITE 2012).
- *Trip link type:* Weekday (and some Saturday) primary, diverted, and pass-by vehicle trip percentages by land use type from *Trip Generation Handbook, 3rd Edition* (ITE 2017b).
- *Trip type (residential):* Residential weekday vehicle trip purpose percentages are available from the 2015 CSTDM by traffic analysis zone (TAZ) (refer to Table G-18). The year 2015 is the most current base year for the CSTDM. Weekday percentages are used for Saturday and Sunday inputs. The user should disclose this limitation in VMT forecasts unless the default

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[11] *Baseline* in this document refers to the definition contained in section 15125 of the CEQA Guidelines.

values are replaced with new documented trip purpose percentages. CalEEMod includes a secondary database of residential trip purpose splits from regional travel demand models from local MPO/RTPAs (refer to Table G-19). These data were supplied by the following local MPO/RTPAs.

  - Butte County Association of Governments
  - Fresno Council of Governments
  - Kern Council of Governments
  - Kings County Council of Governments
  - Madera County Council of Governments
  - Metropolitan Transportation Commission
  - Sacramento Area Council of Governments
  - Southern California Association of Governments
  - San Luis Obispo Council of Governments
  - Tulare County Association of Governments
  - Tahoe Regional Planning Agency

Coverage of the MPO/RTPA database may not spatially extend throughout the entire MPO/RTPA jurisdictional boundary. For example, data from the San Luis Obispo Council of Governments may not be available for every TAZ in their justification. The MPO/RTPA toggle will only activate on the **Vehicle Data** screen if the project is in a TAZ for which there is MPO/RTPA data. Because CalEEMod applies trip characteristics (e.g., vehicle trip purpose splits) at the TAZ spatial scale for the analysis of operational mobile source emissions, MPO/RTPA data may be precluded in the **Operations** module but available for the analysis of construction mobile source emissions, which aggregates defaults for trip lengths to the MPO/RTPA jurisdictional boundary (refer to Section 4.6.2, *Default Values for Vehicle Trip Lengths*).

- *Trip type (non-residential):* Non-residential weekday vehicle trip purpose percentages from the 2015 CSTDM by TAZ or from regional travel demand models from local MPO/RTPAs, where available (refer to Tables G-18 and G-19). Weekday percentages are used for Saturday and Sunday inputs. The user should disclose this limitation in VMT forecasts unless the default values are replaced with new documented trip purpose percentages.

- *Trip length (residential):* Residential weekday vehicle trip lengths from the 2015 CSTDM by TAZ or from regional travel demand models from local MPOs, where available (refer to Tables G-18 and G-19). Weekday data are used for Saturday and Sunday inputs. The user should disclose this limitation in VMT forecasts unless the default values are replaced with new documented trip lengths.

- *Trip length (non-residential):* Non-residential weekday vehicle trip lengths from the 2015 base year of the CSTDM by TAZ or from regional travel demand models from local MPOs, where available (refer to Tables G-18 and G-19). Weekday data are used for Saturday and Sunday inputs.

5.1.1.1.3 Limitations

In addition to select limitations noted above regarding the capture of the ‘project’s effect on VMT,’ other limitations that the user should consider in their CalEEMod applications are listed below.

- *Trip rate:* The ITE vehicle trip rates are not calibrated and validated to California or local project area conditions, nor do they separate passenger and commercial vehicles. The lack of calibration and validation means that ITE rates do not necessarily represent conditions in California, where important variables influencing trip generation, such as income and auto ownership, are higher than other states represented in the data. The user is encouraged to replace these rates with project-specific vehicle trip rates whenever possible. When conducting analysis of projects that will not be operational for many years, the user should also consider current trends in vehicle trip rates and consider whether adjustments are necessary to better reflect expected conditions for the project’s opening or operational year.
- *Trip link type:* The ITE data for primary, diverted, and pass-by rates are limited to a few land use types and does not include complete estimates for all analysis days used in CalEEMod. See Section 5.1.1.2, *Trip and VMT Calculations*, for more details on CalEEMod analysis days.
- *Trip types:* The CSTDM data represents estimated 2015 conditions. The MPO/RTPA data represents the latest year for which data were available from the traffic demand model, which differs among those MPO/RTPAs that provided information. The age of the CSTDM data combined with the recent travel behavior changes caused by COVID-19 responses raises questions about the applicability of the data for baseline and future forecast conditions. In addition, the CSTDM data is limited to TAZ-level values. Vehicle trip purpose splits for individual land uses may vary and may be influenced by the local context of individual project study areas.
- *Trip length (residential):* The CSTDM data represents estimated 2015 conditions. The MPO/RTPA data represents the latest year for which data were available from the traffic demand model, which differs among those MPO/RTPAs that provided information. The age of the CSTDM data raises questions about baseline and future forecast applicability. Further, vehicle trip lengths from CSTDM TAZs may not be sufficiently sensitive to the project land uses and local land use context. Regional travel demand models or mobile device data vendors are alternative sources of vehicle trip length estimates that capture the local context of individual project study areas.
- *MPO/RTPA data:* Trip type percentages and trip lengths provided by MPO/RTPAs truncate data at their demonstrative borders. Also, not all trip purposes (e.g., work-other) may currently occur in a specific MPO TAZ, resulting in a zero value for the default trip distance and purpose split. The user electing to use MPO/RTPA data (if available) should carefully review the TAZ data for reasonableness and applicability to their project.
- *Scale of application:* CalEEMod is designed for individual project site analysis typically involving a single parcel or small group of parcels. Estimates of VMT by CalEEMod at larger scales such as for a specific plan or general plan would result in overestimates of total VMT because the model is not capable of capturing the trip interactions between land uses. CalEEMod only produces gross estimates of total vehicle trips by land use and no process exists to distribute those trips between land uses, which would occur at larger scales.
- *VMT Estimation for SB 743:* In general, CalEEMod is not applicable for SB 743 VMT analysis because most lead agencies elect to follow the Governor’s Office of Planning methodology and threshold recommendations, which require citywide or regionwide VMT estimates. The

use of citywide or regionwide VMT efficiency metrics requires use of travel demand models to establish the threshold value and then to perform the project analysis for consistency with the threshold. CalEEMod cannot produce citywide or regionwide VMT estimates and relies on ITE vehicle trip rates instead of the travel demand model trip rates. The user should also note that SB 743 analysis will tend to focus on automobile only VMT whereas CalEEMod VMT estimates are for total VMT, inclusive of automobile and commercial vehicles, which is required for air quality and GHG analyses under CEQA.

5.1.1.2 Trip and VMT Calculations

This section describes the CalEEMod calculations used to forecast default vehicle trips and VMT to be used when project-specific data are not available.

5.1.1.2.1 Project Location

CalEEMod first identifies in which CSTDM or MPO/RTPA TAZ the project is located. The TAZ selection determines key default inputs related to VMT, specifically the vehicle trip purpose percentages and vehicle trip lengths. CalEEMod automatically identifies the project CSTDM TAZ based on the user defined project location in the **Administrative Map** screen. If MPO/RTPA data are available for the project location and the user elects to use the MPO/RTPA data through the toggle, the model will automatically identify the appropriate MPO/RTPA TAZ.

5.1.1.2.2 Trip Rate

Vehicle trip rate describes the number of trips generated by each land use for the specific analysis day. Multiplying the vehicle trip rate per unit size of land use size (e.g., per DU, per 1,000 sqft) yields total vehicle trips generated by each land use. The ITE trip generation rates are used as defaults in CalEEMod. ITE has guidance about how their trip rates should be used (ITE 2017a). Further, the ITE (2017b) *Trip Generation Handbook* contains procedures for collecting project-specific vehicle trip rates that may more accurately represent the local study area context. The user is encouraged to consult with transportation professionals to develop the best available vehicle trip rates. If more accurate trip rate information is available, the user can override the default trip rate. The user will be required to provide justification from alternative sources of data (e.g., project-specific traffic study) to demonstrate that a different trip rate is appropriate for their project. MPO/RTPAs may be another source of trip generation rates specific for the given region.

Project-generated vehicle trips are used to calculate VMT for either an “average day” or a “peak day.” The average day rates are used when calculating annual emissions from a project, and peak day rates are used when calculating peak daily summer or winter emissions. Since CalEEMod has different trip rates for different days of the week, the peak day is determined based on the highest total of either weekday, Saturday, or Sunday trip emissions. The user should note that this highest day estimate is dependent on the availability of ITE vehicle trip rates, which may not exist for Saturdays or Sundays or have a much smaller sample size for these days. When Saturday or Sunday rates are not available, CalEEMod defaults to weekday rates.

An important limitation of the ITE data for peak day conditions is that it neither includes information about the highest daily vehicle trip generation for a land use subtype, nor details about how vehicle trip generation changes seasonally. These limitations weaken the ability of CalEEMod to represent specific peak daily summer and winter conditions. If peak day summer or winter VMT estimates are essential to the project emissions analysis, then the user should collect vehicle trip generation data for the land use subtypes under analysis during those seasons.

For peak day VMT, CalEEMod chooses the highest vehicle trip rate amongst weekday, Saturday, and Sunday data, and multiplies the rate by the size metric to get total peak day vehicle trips. This product is then multiplied by weekday vehicle trip purpose splits and vehicle trip lengths. If the user has Saturday or Sunday specific input data, those should be substituted accordingly.

5.1.1.2.3 Trip Purpose

Once the total number of vehicle trips for a land use subtype is determined, the next step is to determine the trip purpose percentage breakdown. The trip purpose breakdown represents the proportion of total vehicle trips dedicated to different types of activities such as going to work or shopping. This breakdown is important because activities such as working tend to have longer vehicle trip lengths than activities such as shopping that are often done closer to the home. Multiplying the total trips for a land use subtype by trip purpose breakdown percentage yields vehicle trips of a given trip purpose. Two sets of trip type breakdown are used in CalEEMod: residential and non-residential. Note that these breakdowns do not include separate values for passenger and commercial vehicles.

- *Residential trip purposes*: These include home-work (H-W), home-shop (H-S), and home-other (H-O). A H-W trip represents trips traveling in either direction between home and work locations. A H-S trip represents trips traveling in either direction between home and shopping destinations (generally retail). A H-O trip represents trips traveling in either direction between home and all other locations that are not work or shopping destinations (e.g., school, park, gym). The default residential trip purpose breakdown is from the CSTDM TAZ estimates (refer to Table G-18). CalEEMod includes a secondary database of residential trip purpose splits from regional travel demand models (refer to Table G-19). The user may elect to use the MPO/RTPAs data over the CSTDM data, where available. The user can also prepare more location-specific estimates from traffic study models or mobile device data. The trip purpose breakdown can be overwritten if the user can provide sufficient justification for alternative sources of data (e.g., project-specific traffic study) that demonstrate a different breakdown.

- *Non-residential trip purposes*: Non-residential trip purposes are more complex because of the wide variety of non-residential land use types. For example, a Commercial land use will have a very high percentage of trips associated with H-W, while a Retail land use will have a very low percentage of H-W trips. Most trips to and from a Commercial land use are by employees, while most of the trips to and from a Retail land use are by shoppers. The default non-residential trip purpose breakdown is from the CSTDM TAZ estimates (refer to Table G-18). Non-residential trip purpose splits are also available from many local MPO/RTPAs (refer to Table G-19). The user may elect to use the MPO/RTPA data over the CSTDM data for projects located in these areas. The trip purpose breakdowns represent aggregate proportions of vehicle trip purposes including H-W, work-other (W-O), and other-other (O-O). A H-W trip is the same as defined above for residential. A W-O trip is made by an employee traveling in either direction between a work location and all other locations that are not home. An O-O trip is made by a person traveling in either direction between land uses that do not involve home or work locations.

An important limitation of the non-residential trip purpose estimates is that they are aggregate and may not accurately represent specific land use types. The estimates are derived from TAZs that contain a mix of non-residential land uses. If the non-residential land uses for a project are similar to those within the CSTDM or MPO/RTPA TAZ, then the trip purpose proportions may be reasonable. When land uses differ, then the user should consider whether to adjust the default percentages. The most common adjustments would be to increase the H-W percentage for land uses where most vehicle trips are generated by employees and thus decreasing the other trip purposes. Likewise, shopping related land uses may need to have lower H-W and W-O percentages and higher O-O percentages. For example, trip purpose splits shown in Table C-7 were developed by the Transportation Research Board (2021). The comparison demonstrates the general differences between retail and service land uses.

Table C-7. Vehicle Trip Purpose Split Comparison for Retail versus Service Land Uses

Trip Purpose	Retail [a]	Service (e.g., Commercial) [b]
H-W	15%	26%
W-O	54%	53%
O-O	32%	21%

H-W = home-work; O-O = other-other; W-O = work-other

[a] Retail includes North American Industry Classification System (NAICS) codes 44-45.

[b] Service includes NAICS codes 52-92.

The user should note that differences can be much larger than shown in Table C-7. As evidence, consider TAZ 1064 from the CSTDM. This TAZ has a H-W trip purpose split of 71 percent. This high value is due to the large amount (over 5,000) and concentration of office employees in the TAZ compared to other non-residential uses. If a project involved adding more office space to this TAZ, the current split may be reasonable, whereas, adding a retail land use could increase the proportion of W-O and O-O. As with other default inputs, trip purpose breakdown can be overwritten by the user.

5.1.1.2.4 Trip Length

5.1.1.2.4.1 Primary Trip Length

Each trip type has a primary trip length associated with it, which is the full distance from the trip origin to the trip destination with no intermediate stops. These trip lengths are based on the CSTDM or MPO/RTPA TAZ in which the project is located (refer to Tables G-18 and G-19). For residential projects, average primary vehicle trip lengths of all trip types are determined with the following equation. Non-residential land use types use a similar equation based on their trip types.

$$PTL_i = \text{H-W}_{miles} \times \text{H-W}_{trip\%} + \text{H-S}_{miles} \times \text{H-S}_{trip\%} + \text{H-O}_{miles} \times \text{H-O}_{trip\%}$$

Where:

PTL = average primary trip length.

$H\text{-}W_{miles}$ = H-W trip length.

$H\text{-}W_{trip\%}$ = % of the total primary trips that are H-W trips.

$H\text{-}S_{miles}$ = H-S trip length.

$H\text{-}S_{trip\%}$ = % of the total primary trips that are H-O trips.

$H\text{-}O_{miles}$ = H-O trip length.

$H\text{-}O_{trip\%}$ = % of the total primary trips that are H-O trips.

i = land use subtype.

5.1.1.2.4.2 Adjustment for Trip Link Type

Trip link types describe the characteristics of the vehicle trip attracted to each land use subtype, whether it is a primary trip, a diverted link trip, or a pass-by trip. Primary trips contain no intermediate stops. For example, a trip from home to work without any stops along the way would be 100 percent primary. In contrast, a commercial customer stopping for coffee on their way to work would represent a pass-by trip for the coffee shop, presuming the coffee shop was already on the same travel route to work. Hence, pass-by trips generate virtually no additional running emissions but could generate additional resting and startup emissions. Diverted trips involve a short diversion from the original travel route, which generates a small amount of running emissions while also generating additional resting and startup emissions. The VMT associated with a trip is adjusted by modifying the primary trip length to account for reductions from pass-by and diverted trips. The vehicle trip lengths mentioned above obtained from the CSTDM or MPO/RTPA database are for primary trip links. For pass-by trip links the vehicle trip length is 0.1 mile. For diverted trip links, the vehicle trip length is 2 miles. This value represents the typical diversion from a freeway to adjacent highway commercial uses for urban/suburban areas. Diverted trips from arterials may be shorter or longer depending on the type of project and the study area roadway configuration. Note that only the primary trip lengths have data fields presented on the **Vehicle Data** screen. The diverted link trip length (2 miles), and pass-by trip length (0.1 mile) are constants stored in the backend of the model.

The trip link percentages in CalEEMod are from the *3rd Edition Trip Generation Handbook* (ITE Handbook) (ITE 2017b) (refer to Table G-20). Not all land use subtypes or analysis days (e.g., weekday, Saturday, and Sunday) are included in the ITE Handbook so the user should carefully review the information. The trip link percentages can be overwritten if the user can provide justification for alternative sources of data (e.g., project-specific traffic study) that demonstrate different breakdowns. The ITE Handbook does not contain trip link percentages for 83 of the non-linear land use subtypes used in CalEEMod. In most cases, these land use subtypes were coded as having 100 percent primary trips. This default minimizes the potential for underestimation of VMT but could contribute to overestimation. If land use subtypes are similar—i.e., Movie Theater (No Matinee) may have similar trip patterns as Quality Restaurant—then the user can consider replacing the land use subtype with missing diverted or pass-by percentages with the percentages of the similar land use subtype. Likewise, if diverted or pass-by trips are not desired for those land use subtypes where defaults are given, the user can change the default percentages to 0 and have primary equal 100 percent. Since ITE did not include any diverted or pass-by percentages for Sundays, the Saturday values were substituted to minimize the potential for substantially overestimating Sunday VMT.

5.1.1.3 Example VMT and Trips Calculation

The following example shows each step of how CalEEMod calculates the annual average day and peak day VMT and trips for a Regional Shopping Center land use subtype.[12] Both of these outputs are needed to calculate mobile running, mechanical, and evaporative emissions. Figure C-2 illustrates these steps.

1. The user enters project location on the **Home** screen and the land use subtype and unit amount on the **Land Use** screen.

   Location = Sacramento (CSTDM TAZ 660)

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[12] Results in each equation are the product of calculations performed within CalEEMod and may not match manual computations using rounded values.

Land Use Subtype = Regional Shopping Center (ITE Land Use Code 820)

Unit = 1000 sqft (KSF)

Size = 75 (i.e., 75,000 sqft)

2. CalEEMod will return the following defaults on the **Vehicle Data** screen based on the inputs from step 1 above.

   - Weekday, Saturday, and Sunday average vehicle trip rates

     37.75 trips per weekday per unit (KSF)

     46.12 trips per Saturday per unit (KSF)

     21.10 trips per Sunday per unit (KSF)

   - Weekday vehicle primary trip lengths. As noted above, diverted and pass-by trip lengths are constants stored in the backend of the model. Also, residential trip lengths are zeroed out because the project's land use type is non-residential.

     10.06 miles per Non-Res H-W trip

     7.69 miles per Non-Res W-O trip

     6.44 miles per Non-Res O-O trip

     0.00 miles per Res H-W trip

     0.00 miles per Res H-S trip

     0.00 miles per Res H-O trip

   - Weekday and Saturday primary, diverted, and pass-by percentages. Saturday values are also used for Sunday estimates.

     37.9% for primary weekday trips

     28.1% for diverted weekday trips

     34.0% for pass-by weekday trips

     42.5% for primary Saturday trips

     31.5% for diverted Saturday trips

     26.0% for pass-by Saturday trips

   - Vehicle trip purpose percentages. Residential trip lengths are zeroed because the project's land use type is non-residential.

     17.4% for Non-Res H-W primary weekday trips

     9.0% for Non-Res W-O primary weekday trips

     73.5% for Non-Res O-O primary weekday trips

     0.0% for Res H-W primary weekday trips

     0.0% for Res W-O primary weekday trips

     0.0% for Res O-O primary weekday trips

3. CalEEMod calculates the number of primary, diverted, and pass-by vehicle trips for each analysis day using the following equations.

$$\text{Weekday}_{\text{primary}} = 75\text{ KSF} \times 37.75\text{ trips/KSF} \times 37.9\% = 1{,}074\text{ trips/day}$$

$$\text{Saturday}_{\text{primary}} = 75\text{ KSF} \times 46.12\text{ trips/KSF} \times 42.5\% = 1{,}470\text{ trips/day}$$

$$\text{Sunday}_{\text{primary}} = 75\text{ KSF} \times 21.10\text{ trips/KSF} \times 42.5\% = 673\text{ trips/day}$$

$$\text{Weekday}_{\text{diverted}} = 75\text{ KSF} \times 37.75\text{ trips/KSF} \times 28.1\% = 795\text{ trips/day}$$

$$\text{Saturday}_{\text{diverted}} = 75\text{ KSF} \times 46.12\text{ trips/KSF} \times 31.5\% = 1{,}089\text{ trips/day}$$

$$\text{Sunday}_{\text{diverted}} = 75\text{ KSF} \times 21.10\text{ trips/KSF} \times 31.5\% = 498\text{ trips/day}$$

$$\text{Weekday}_{\text{pass-by}} = 75\text{ KSF} \times 37.75\text{ trips/KSF} \times 34.0\% = 963\text{ trips/day}$$

$$\text{Saturday}_{\text{pass-by}} = 75\text{ KSF} \times 46.12\text{ trips/KSF} \times 26.0\% = 899\text{ trips/day}$$

$$\text{Sunday}_{\text{pass-by}} = 75\text{ KSF} \times 21.10\text{ trips/KSF} \times 26.0\% = 411\text{ trips/day}$$

4. CalEEMod determines the total trips per day for Weekday, Saturday, and Sunday by summing the outputs from step 3 above. CalEEMod selects the peak day trip from these totals to quantify daily mobile source evaporative emissions.

$$\text{Weekday}_{\text{total}} = 1{,}074 + 795 + 963 = 2{,}831\text{ trips/day}$$

$$\text{Saturday}_{\text{total}} = 1{,}470 + 1{,}089 + 899 = 3{,}459\text{ trips/day}$$

$$\text{Sunday}_{\text{total}} = 673 + 498 + 411 = 1{,}582\text{ trips/day}$$

$$\text{Peak day Trips} = \text{Saturday}_{\text{total}} = 3{,}459\text{ trips/day}$$

5. CalEEMod calculates annual trips from step 4 above using the following equations. The annual trips total is used to quantify annual mobile source evaporative emissions.

$$\text{Annual Trips}_{\text{weekday}} = 2{,}831\text{ trips/day} \times 5\text{ days/week} \times 52.1429\text{ weeks/year} = 738{,}148\text{ trips/year}$$

$$\text{Annual Trips}_{\text{Saturday}} = 3{,}459\text{ trips/day} \times 1\text{ day/week} \times 52.1429\text{ weeks/year} = 180{,}362\text{ trips/year}$$

$$\text{Annual Trips}_{\text{Sunday}} = 1{,}582\text{ trips/day} \times 1\text{ day/week} \times 52.1429\text{ weeks/year} = 82{,}516\text{ trips/year}$$

$$\text{Annual Trips}_{\text{total}} = 738{,}148 + 180{,}362 + 82{,}516 = 1{,}001{,}026\text{ trips/year}$$

6. CalEEMod multiplies the primary vehicle trip rates from step 3 above by the vehicle trip purpose percentages to (i.e., $\text{Weekday}_{\text{primary}}$ above is the sum of the below Weekday $\text{H-W}_{\text{primary}}$, Weekday $\text{W-O}_{\text{primary}}$, and Weekday $\text{O-O}_{\text{primary}}$) using the following equations.

$$\text{Weekday H-W}_{\text{primary}} = 1{,}074\text{ trips/day} \times 17.4\% = 187\text{ trips/day}$$

$$\text{Weekday W-O}_{\text{primary}} = 1{,}074\text{ trips/day} \times 9.0\% = 97\text{ trips/day}$$

$$\text{Weekday O-O}_{\text{primary}} = 1{,}074\text{ trips/day} \times 73.5\% = 790\text{ trips/day}$$

$$\text{Saturday H-W}_{\text{primary}} = 1{,}470\text{ trips/day} \times 17.4\% = 256\text{ trips/day}$$

$$\text{Saturday W-O}_{\text{primary}} = 1{,}470 \text{ trips/day} \times 9.0\% = 133 \text{ trips/day}$$

$$\text{Saturday O-O}_{\text{primary}} = 1{,}470 \text{ trips/day} \times 73.5\% = 1{,}081 \text{ trips/day}$$

$$\text{Sunday H-W}_{\text{primary}} = 673 \text{ trips/day} \times 17.4\% = 117 \text{ trips/day}$$

$$\text{Sunday W-O}_{\text{primary}} = 673 \text{ trips/day} \times 9.0\% = 61 \text{ trips/day}$$

$$\text{Sunday O-O}_{\text{primary}} = 673 \text{ trips/day} \times 73.5\% = 495 \text{ trips/day}$$

7. CalEEMod multiplies the vehicle trips from step 6 above by vehicle trip lengths using the following equations.

$$\text{Weekday H-W VMT}_{\text{primary}} = 187 \text{ trips/day} \times 10.06 \text{ miles/trip} = 1{,}883 \text{ miles/day}$$

$$\text{Weekday W-O VMT}_{\text{primary}} = 97 \text{ trips/day} \times 7.69 \text{ miles/trip} = 745 \text{ miles/day}$$

$$\text{Weekday O-O VMT}_{\text{primary}} = 790 \text{ trips/day} \times 6.44 \text{ miles/trip} = 5{,}083 \text{ miles/day}$$

$$\text{Weekday VMT}_{\text{diverted}} = 795 \text{ trips/day} \times 2.0 \text{ miles/trip} = 1{,}590 \text{ miles/day}$$

$$\text{Weekday VMT}_{\text{pass-by}} = 963 \text{ trips/per day} \times 0.1 \text{ mile/trip} = 96 \text{ miles/day}$$

$$\text{Weekday VMT}_{\text{total}} = 1{,}883 + 745 + 5{,}083 + 1{,}590 + 96 = 9{,}397 \text{ miles/day}$$

$$\text{Saturday H-W VMT}_{\text{primary}} = 256 \text{ trips/day} \times 10.06 \text{ miles/trip} = 2{,}579 \text{ miles/day}$$

$$\text{Saturday W-O VMT}_{\text{primary}} = 133 \text{ trips/day} \times 7.69 \text{ miles/trip} = 1{,}020 \text{ miles/day}$$

$$\text{Saturday O-O VMT}_{\text{primary}} = 1{,}081 \text{ trips/day} \times 6.44 \text{ miles/trip} = 6{,}961 \text{ miles/day}$$

$$\text{Saturday VMT}_{\text{diverted}} = 1{,}089 \text{ trips/day} \times 2.0 \text{ miles/trip} = 2{,}178 \text{ miles/day}$$

$$\text{Saturday VMT}_{\text{pass-by}} = 899 \text{ trips/day} \times 0.1 \text{ mile/trip} = 90 \text{ miles/day}$$

$$\text{Saturday VMT}_{\text{total}} = 2{,}579 + 1{,}020 + 6{,}961 + 2{,}178 + 90 = 12{,}829 \text{ miles/day}$$

$$\text{Sunday H-W VMT}_{\text{primary}} = 117 \text{ trips/day} \times 10.06 \text{ miles/trip} = 1{,}180 \text{ miles/day}$$

$$\text{Sunday W-O VMT}_{\text{primary}} = 61 \text{ trips/day} \times 7.69 \text{ miles/trip} = 467 \text{ miles/day}$$

$$\text{Sunday O-O VMT}_{\text{primary}} = 495 \text{ trips/day} \times 6.44 \text{ miles/trip} = 3{,}185 \text{ miles/day}$$

$$\text{Sunday VMT}_{\text{diverted}} = 498 \text{ trips/day} \times 2.0 \text{ miles/trip} = 997 \text{ miles/day}$$

$$\text{Sunday VMT}_{\text{pass-by}} = 411 \text{ trips/day} \times 0.1 \text{ mile/trip} = 41 \text{ miles/day}$$

$$\text{Sunday VMT}_{\text{total}} = 1{,}180 + 467 + 3{,}185 + 997 + 41 = 5{,}869 \text{ miles/day}$$

8. CalEEMod selects the peak day trip from step 7 above to quantify daily mobile source running and mechanical emissions.

$$\text{Peak day VMT} = \text{Saturday VMT}_{\text{total}} = 12{,}829 \text{ miles/day}$$

9. CalEEMod calculates annual VMT from step 7 above using the following equations. The annual VMT total is used to quantify annual mobile source running and mechanical emissions.

$$\text{Annual VMT}_{\text{weekday}} = \text{9,397 miles/day} \times \text{5 days/week} \times \text{52.1429 weeks/year} = \text{2,449,948 miles/year}$$

$$\text{Annual VMT}_{\text{Saturday}} = \text{12,829 miles/day} \times \text{1 day/week} \times \text{52.1429 weeks/year} = \text{668,947 miles/year}$$

$$\text{Annual VMT}_{\text{Sunday}} = \text{5,869 miles/day} \times \text{1 day/week} \times \text{52.1429 weeks/year} = \text{306,045 miles/year}$$

$$\text{Annual VMT}_{\text{total}} = \text{2,449,948} + \text{668,947} + \text{306,045} = \text{3,424,938 miles/year}$$

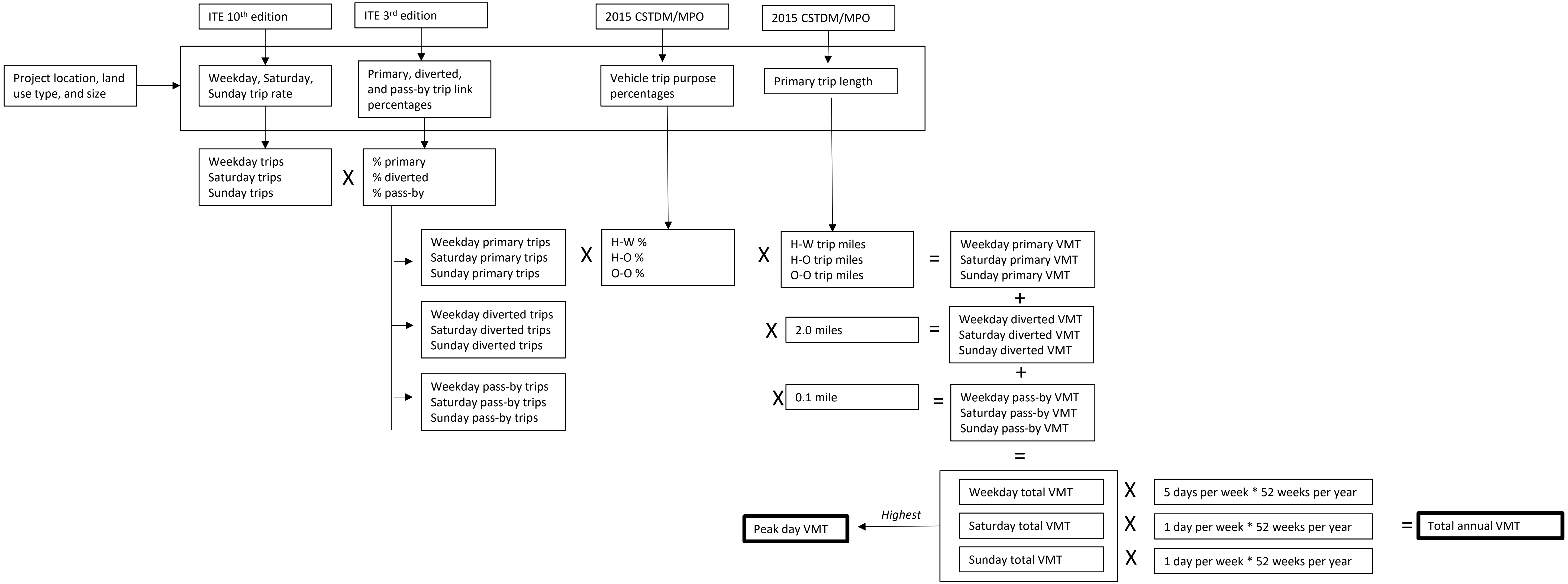

Figure C-2. Vehicle Miles Traveled Calculation Method

5.1.2 Fleet Mix Screen

This screen displays for the operational analysis year the default vehicle fleet mix by land use type and season (Annual, Summer, and Winter). The default fleet mix is based on data from EMFAC2021 for the user-selected analysis level (e.g., county) and operational year (e.g., 2030).

5.1.3 Vehicle Emission Factors Screen

All vehicle emission factors, except those for HFCs, are based on EMFAC2021 v1.0.1 (CARB 2021d). EMFAC2021 emission rate data for each vehicle class includes multiple emission types that are presented with varying units. Running and mechanical emissions are presented in units of grams per mile (g/mile), while starting and evaporative emissions are presented in units of grams per trip (g/trip), and idling emissions are presented in units of grams per vehicle per day (g/vehicle/day). The emission rate data in EMFAC2021 is not readily available in a format that is compatible with CalEEMod vehicle emission factor formats. In addition, EMFAC2021 emission rate data is presented for vehicle class and fuel type combinations while CalEEMod vehicle emission factors are aggregated over all fuel types for each vehicle class. Thus, emission rates output by EMFAC2021 are not directly used. Rather, post-processed EMFAC2021 emission inventory and activity data are the basis for CalEEMod vehicle emission factors. Emission type and fuel type data are aggregated for each vehicle class to develop emission factors by vehicle class for use in CalEEMod.

The following sections describe the methodology by which EMFAC2021 emissions inventory and activity data were processed to develop vehicles emission rates for CalEEMod. Following this, the equations and variables used to develop emission factors for HFC and road dust are provided.

5.1.3.1 Vehicle Emission Factors from EMFAC2021

5.1.3.2 EMFAC2021 Emissions Inventory Data

For each desired calendar year (2010–2050), vehicle model year, vehicle type and season (Annual, Summer, and Winter), detailed daily EMFAC2021 inventory outputs were provided by CARB in MySQL database format for the following geographies: counties, air basins, air districts and statewide for all fuel types (e.g., gasoline, diesel, and electric). The EMFAC2021 MySQL emissions data were provided for the aggregated speed option. The EMFAC2021 MySQL emissions data is the basis of CalEEMod emission factors.

5.1.3.3 EMFAC2021 Emissions Inventory Units versus CalEEMod Emission Factor Units

In CalEEMod, running emission factors for all pollutants and PM emissions from tire and brake wear are in units of grams per vehicle miles traveled (g/VMT). For all other emission types, emission factors are in units of g/trip (derived as total emissions divided by the total number of trips). Table C-8 summarizes the acronyms, descriptions, and units of each vehicle emission type and activity in EMFAC2021 and the corresponding emission factor units as presented in CalEEMod.

Table C-8. EMFAC2021 Emission Types and Activity

EMFAC2021 Acronyms for Each Vehicle Emission Type	EMFAC2021 Description of Each Vehicle Emission Type	EMFAC2021 Emission Rate Unit	CalEEMod Emission Factor Unit
RUNEX	Running exhaust	short tons/day	g/mile
PMBW	PM brakewear	short tons/day	g/mile
PMTW	PM tirewear	short tons/day	g/mile
STREX	Start exhaust	short tons/day	g/trip
HTSK	Hot Soak evaporative	short tons/day	g/trip
RUNLS	Running Loss evaporative	short tons/day	g/trip
IDLEX	Idle exhaust	short tons/day	g/trip
RESTL	Resting Loss evaporative	short tons/day	g/trip
DIURN	Diurnal Loss evaporative	short tons/day	g/trip
VMT	Vehicle miles traveled	miles/day	miles (per day, per season, or per year)
Trip	Total trips per day of a vehicle class	trips/day	trips (per day, per season, or per year)
Population	Vehicle population	vehicle	vehicle

5.1.3.4 Conversion from EMFAC2021 Emissions Inventory to CalEEMod Emission Factors

EMFAC2021 emissions are disaggregated by fuel types while CalEEMod vehicle emission factors are aggregated across fuel types. Therefore, CalEEMod emission factors were estimated based on average EMFAC2021 emission rates for each vehicle type, weighted according to annual VMT, annual trips, or vehicle population.

CalEEMod emission factors for each emission mode by vehicle class were calculated based on EMFAC2021 emissions inventory output according to the following equations. Emission factors were combined across fuel types for each emission mode by weighting according to the same activity types (i.e., VMT or trips) as applied in the following equations.

CalEEMod emission factors of all vehicle classes are calculated according to the following equations.

$$\mathrm{RUNEX}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{RUNEX}_{\mathrm{DailyEmissions}}}{\mathrm{VMT}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{VMT}_{i,j}}{\sum \mathrm{VMT}}\right]$$

$$\mathrm{PMBW}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{PMBW}_{\mathrm{DailyEmissions}}}{\mathrm{VMT}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{VMT}_{i,j}}{\sum \mathrm{VMT}}\right]$$

$$\mathrm{PMTW}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{PMTW}_{\mathrm{DailyEmissions}}}{\mathrm{VMT}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{VMT}_{i,j}}{\sum \mathrm{VMT}}\right]$$

$$\mathrm{STREX}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{STREX}_{\mathrm{DailyEmissions}}}{\mathrm{Trips}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{Trips}_{i,j}}{\sum \mathrm{Trips}}\right]$$

$$\mathrm{HTSK}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{HTSK}_{\mathrm{DailyEmissions}}}{\mathrm{Trips}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{Trips}_{i,j}}{\sum \mathrm{Trips}}\right]$$

$$\mathrm{DIURN}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{DIURN}_{\mathrm{DailyEmissions}}}{\mathrm{Trips}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{Trips}_{i,j}}{\sum \mathrm{Trips}}\right]$$

$$\mathrm{RESTL}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{REST}_{\mathrm{DailyEmissions}}}{\mathrm{Trips}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{Trips}_{i,j}}{\sum \mathrm{Trips}}\right]$$

$$\mathrm{RUNLS}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{RUNLS}_{\mathrm{DailyEmissions}}}{\mathrm{Trips}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{VMT}_{i,j}}{\sum \mathrm{VMT}}\right]$$

$$\mathrm{IDLEX}_{\mathrm{CalEEMod}} = \sum_{i,j}\left[\left(\frac{\mathrm{IDLEX}_{\mathrm{DailyEmissions}}}{\mathrm{Trips}} \times \mathrm{UC}\right)_{i,j} \times \frac{\mathrm{Pop}_{i,j}}{\sum \mathrm{Pop}}\right]$$

Where:

$RUNEX_{CalEEMod}$, $PMBW_{CalEEMod}$, $PMTW_{CalEEMod}$, $STREX_{CalEEMod}$, $HTSK_{CalEEMod}$, $RUNLS_{CalEEMod}$, $IDLEX_{CalEEMod}$, $DIURN_{CalEEMod}$, $RESTL_{CalEEMod}$ = CalEEMod vehicle emission factors by vehicle class or vehicle class grouping (g/mi or g/trip).

Daily Emissions = total pollutant emissions (short tons/day) output from EMFAC2021 by vehicle class.

VMT = total VMT (miles/day) output from EMFAC2021 by vehicle class.

Trips = total number of trips (trips/day) output from EMFAC2021 by vehicle class.

Pop = total number of vehicles (number) with non-zero idling emissions per day output from EMFAC2021 by vehicle class.

UC = conversion factor from short tons to grams (90,7184.740760757 g/short ton).

i = fuel type.

j = model year.

5.1.3.5 HFC Emission Factors

HFCs are organic compounds that contain fluorine and hydrogen atoms and are mainly used as refrigerants in air conditioning (A/C) systems. HFCs are a type of GHG with global warming potentials (GWP) up to thousands of times larger than CO_2. HFC emissions (assumed to be HFC-134a) from on-road mobile sources are primarily from refrigerant leakage, which increases when A/C units are in operation.

HFC emission factors are based on information provided by CARB (2017c) and are calculated using a top-down approach (i.e., the factors are derived from total emission inventory estimates and activity data). CARB estimated that the annual HFC-134a emissions were 49 grams per year from each light-duty vehicle (LDV), and 257 grams per year from each heavy-duty vehicle (HHDV) (CARB 2007; CARB 2017c). These estimates reflect three assumptions.

1. Vehicle A/C operates during 5 summer (or relatively warm) months per year.
2. The winter (or relatively cold) month emission rate is 18 percent of the summer month emission rate.
3. The in-use A/C operates on average for 1 hour in LDVs per weekday and for 8 hours in HHDVs on all days of the week.

CARB then estimated the average (statewide) leakage rates, as shown in Table C-9. HFC emission factors are calculated as a running loss rate (g/hr) and can be converted to a g/mile rate by assuming a fleet-average vehicle speed.

Table C-9. Statewide Hydrofluorocarbon (HCF) Leak Rates for Light- and Heavy-Duty Vehicles

Air Conditioning Operation	Light-Duty Vehicles (g HFC-134a/hour)	Heavy-Duty Vehicles (g HFC-134a/hour)
On	0.0616	0.1512
Off	0.0089	0.0218
Weighted average	0.031	0.076

Under USEPA’s Significant New Alternatives Policy (SNAP), HFC-134a must be replaced by refrigerants with much lower GWPs. The use of HFC-134a is forbidden in new light-duty vehicles starting in 2021 and forbidden in all new vehicles starting in 2026. The SNAP requirement does not apply to existing vehicles. As a result, HFC emissions from on-road vehicles will decrease over time as new vehicles with alternative refrigerants are introduced into the vehicle fleet, and as older vehicles with HFC refrigerants are retired from the fleet.

The following steps were taken to develop HFC emission factors by vehicle category (VC) for each geographic area (A), calendar year (Y), and season (S) ($\mathrm{EF(HFC, A, Y, S)}_{\mathrm{RUNLOSS}}^{\mathrm{VC}}$) for CalEEMod.

1. The weighted-average HFC leakage rate for LDV (0.031 g/h) was used for the Non-Truck category, and the weighted average HFC leakage rate for HHDV (0.076 g/hr) was used for both Truck 1 and Truck 2 categories. Truck/Non-Truck emission factors were mapped to their corresponding EMFAC 2021 vehicle classes, and the associated VMT data, which was obtained from EMFAC2021.
2. HFC emission factors were set to 0 for 2021 and later model year (MY) LDV and for 2026 and later MYs HHDV, per USEPA's SNAP regulation.
3. For each vehicle category, geographic area, calendar year, and season, the emission factor (g/mi) was calculated as a weighted average emission rate based on VMT.

$$\mathrm{EF(HFC,A,Y,S)}^{\mathrm{VC}} = \frac{\sum_{\mathrm{v}} \mathrm{ER}_{\mathrm{On}}^{\mathrm{VC(MY)}} \times \mathrm{VMT(A,Y,S)}^{\mathrm{v}(\Sigma,\mathrm{MY})}}{\sum_{\mathrm{v}} \mathrm{VMT(A,Y,S)}^{\mathrm{v}(\Sigma,\mathrm{MY})} \times \bar{\mathrm{v}}\mathrm{(A,Y,S)}^{\mathrm{v}(\Sigma,\mathrm{MY})}}$$

Where:

EF = HFC emission factor (g/mile).

ER = HFC leakage (emission) rate (g/hr).

VC = vehicle category factor (g/mile).

VMT = vehicle miles traveled (miles).

$\bar{v}$ = mean vehicle category speed (mph).

A = geographic area.

Y = calendar year.

S = season.

MY = model year.

The mean vehicle speed is used to convert the emission factor from a running loss factor (g/hr) to g/mile and was calculated for each area and year from the default VMT speed distributions in EMFAC2021. Emission factors calculated for EMFAC 2021 vehicle classes were traced to their analogous EMFAC2007 vehicle classes.

1. HFC emission factors for each geographic area were mapped to their corresponding air district and air basin, and aggregated, resulting in emission factors for each district and basin, for each vehicle category, calendar year, and season. In addition, statewide emission factors for each vehicle category, calendar year, and season were calculated by aggregating emission factors from every geographic area.
2. HFC emission factors by season were then derived assuming that:
   - On average, A/C is on for 5 "hot" months and off for 7 "cold" months during the year. This results in seasonal weighting factors of $^{5}/_{12} = 0.41667$ for A/C-On and $^{7}/_{12} = 0.58333$ for A/C-Off.
   - The emission factors for "hot" months are used for summer emission factors, and the emission factors for "cold" months are used for winter emission factors.
   - The seasonal weighting factors are used to generate annual emission factors. This approach is consistent with the methods used by CARB to develop the annual emissions inventory.

3. For areas where Urban Bus (UBUS) VMT data was unavailable in EMFAC2021, the “Other Buses” (OBUS) HFC emission factors for the corresponding area and year were substituted as replacement values for years before 2020.

5.1.4 Road Dust Screen

Vehicles that drive on both paved and unpaved roads generate fugitive dust by dispersing the silt from the roads. Fugitive dust emission factors for travel on paved roads are calculated using the methodology described in Section 13.2.1 of USEPA’s AP-42, as shown below (USEPA 2011).

$$EF_{paved} = (k \times (sL)^{0.91} \times (W)^{1.02}) \times (1 - P/4N)$$

Where:

EF_{paved} = paved road dust emission factor (g/mile).

k = particle size multiplier for particle size range. The AP-42 default values are 0.25 g/VMT for PM2.5 and 1.00 g/VMT for PM10.

sL = road surface silt loading (g/m^2). The AP-42 default value is 0.1 g/m^2, which corresponds to vehicle travel on roads with at least 5,000 vehicle per day under normal conditions.

W = average weight (short tons) of *all the vehicles* traveling the road. The statewide default is 2.4 short tons (CARB 2021e).

P = number of “wet” days with at least 0.254 mm (0.01 in) of precipitation during the averaging period. The precipitation frequency is based on the project location and is listed on the **Project Detail** screen.

N = number of days in the averaging period (e.g., 365 for annual, 91 for quarterly). The model does not include a precipitation adjustment in the daily calculation.

Fugitive dust emission factors for travel on *unpaved* roads are calculated using the methodology described in Section 13.2.2 of USEPA’s AP-42, as shown below (USEPA 2006b).

$$EF_{unpaved} = \left(\frac{k(s/12)^{1}(S/30)^{0.5}}{(M/0.5)^{0.2}} - C\right) \times (1 - \frac{P}{365})$$

Where:

$EF_{unpaved}$ = unpaved road dust emission factor (g/mile).

k = particle size multiplier for particle size range. The AP-42 default values are 816.47 g/VMT for PM2.5 and 81.65 g/VMT for PM10.

s = surface material silt content (%). The model assumes the AP-42 default of 8.5 for scraper routes unless the project is in the San Luis Obispo Air Pollution Control District (SLOAPCD). For projects located in the SLOAPCD, the model defaults to 9.3 per air district guidance.

M = surface material moisture content (%). The model assumes a default average moisture content of 0.5 unless the project is in the SLOAPCD. For projects located in the SLOAPCD, the model defaults to 0.1 per air district guidance.

S = mean vehicle speed (mph). The model assumes a default average speed of 40 mph unless the project is in the SLOAPCD. For projects located in the SLOAPCD, the model defaults to 32.4 mph per air district guidance.

C = emission factor for vehicle fleet exhaust, brakewear, and tirewear.

P = number of days in a year with at least 0.254 mm (0.01 in) of precipitation. The precipitation frequency is based on the project location and is listed on the **Project Detail** screen.

By default, CalEEMod assigns project VMT to unpaved and paved roads based on the percentage of paved and unpaved roads at the user-selected analysis scale (refer to Table G-21). The user may modify the percentage of unpaved roads if project-specific information is available. Likewise, the user may elect to use emission factors from CARB's statewide emission inventory, which are 2.0 lb PM10/VMT and 0.2 lb PM2.5/VMT.

5.1.5 Mobile Source Emissions Quantification

CalEEMod emissions from mobile sources are calculated using the emission factors described in the previous sections and the forecasted vehicle trips and VMT for the project (either input directly by the user or generated according to the method described in Section 5.1.1.1, *Default Vehicle Trips and VMT*).

Running, mechanical (i.e., tirewear and brakewear), and road dust emissions are calculated according to the following equation.

$$E_p = EF_p \times VMT$$

Where:

E = running and mechanical emissions (g/day or g/yr).

EF = emission factor (g/VMT).

VMT = vehicle miles traveled (miles/day or miles/yr).

p = pollutant.

Starting, evaporative, and idling emissions are calculated according to the following equation.

$$E_p = EF_p \times Trip$$

Where:

E = starting, evaporative, and idling emissions (g/day or g/yr).

EF = emission factor (g/trip).

Trip = trips (trips/day or trips/yr).

p = pollutant.

5.2 Area Sources Submodule

The **Area Sources** submodule calculates operational emissions from hearths, consumer products, architectural coatings, and landscape equipment. Emissions associated with natural gas usage in space heating, water heating, and stoves are calculated in the **Energy Use** screen (see Section 5.3.1, *Energy Use Screen*).

5.2.1 Hearths Screen

CalEEMod calculates the emissions from wood stoves and fireplaces. Available wood stove fuel types are conventional, catalytic, non-catalytic, and pellet. The fireplace fuel types are wood, gas, propane, and electric. All fuel types are considered non-biogenic except for wood. CO_2 emissions from the combustion of wood (or biomass) are considered biogenic. Some protocols do not consider these emissions to be a part of the emission inventory. Therefore, CalEEMod reports these CO_2 emissions separate from anthropogenic GHG emissions.

Default values related to hearth activity are available for Residential land use types. The defaults vary by Residential land use type (e.g., Single Family Housing) and air district, though there are also statewide defaults. The default values for the number of wood stoves or hearths (i.e., number of devices installed in all DUs), the amount of wood burned by different hearth types, and the daily and annual duration of activity are based on CARB (2011) and air district supplied values (refer to Table G-22).

Hearth emission factors are based on various sources (USEPA 1996a; USEPA 1996b; USEPA 2015; USEPA 2020) (refer to Table G-23). The following sections provide further detail on the quantification of these emissions by hearth type.

5.2.1.1 Wood Stoves and Wood Fireplaces

The equation to calculate the annual biogenic GHG emissions associated with all wood stove types and wood fireplaces is shown below.

$$E_{SWF} = EF_{SWF} \times UC_1 \times W \times UC_2 \times SWF$$

Where:

E_{SWF} = wood stove or wood fireplace biogenic GHG emissions (MT/yr).

EF_{SWF} = wood stove or wood fireplace emissions factor (lb/short ton wood) (USEPA 1996a; USEPA 1996b; CARB 2011) (Table G-23).

UC_1 = unit conversion from lb to MT (0.00045359290943564 MT/lb).

W = wood burned (lb/unit/yr).

UC_2 = unit conversion from lb to short ton (0.0005 short ton/lb).

SWF = number of this type of wood stove or wood fireplace in the project.

The emission factors for criteria pollutants are derived from the same sources as the GHG emission factors (USEPA 1996a; USEPA 1996b). The only difference in the equation for criteria pollutant emissions is the unit conversion, as GHG emissions are presented in MT per year and criteria pollutant emissions are presented in short tons per year.

5.2.1.2 Natural Gas and Propane Fireplaces

The equation to calculate the annual non-biogenic GHG emissions associated with natural gas and propane fireplaces is shown below.

$$E_{GPF} = EF_{GPF} \times H \times D \times R \times UC \times GPF$$

Where:

E_{GPF} = natural gas or propane fireplace non-biogenic GHG emissions (MT/yr).

EF_{GPF} = natural gas or propane fireplace non-biogenic GHG emissions factor (lb/MMbtu) (USEPA 2020) (Table G-23).

H = daily duration of fireplace activity (hr/day).

D = annual duration of fireplace activity (days/yr).

R = heating rate (0.06 MMBtu/hr) (South Coast AQMD 2008).

UC = unit conversion from lb to MT (0.00045359290943564 MT/lb).

GPF = number of natural gas or propane fireplaces in the project.

The two differences between the equation for non-biogenic GHG emissions and criteria pollutant emissions are the emission factor source (USEPA 1998a) and the unit conversion, as GHG emissions are presented in MT per year and criteria pollutant emissions are presented in short tons per year. The criteria pollutant emission factors are derived by assuming natural gas has 1,020 BTU per standard cubic foot.

5.2.1.3 Electric Fireplaces

The equation to calculate the annual non-biogenic GHG emissions associated with electric fireplaces is shown below.

$$E_{EF} = U_{EF} \times E \times UC_1 \times UC_2 \times GPF$$

Where:

E_{EF} = electric fireplace non-biogenic GHG emissions (MT/yr).

U_{EF} = carbon intensity of electric utility (lb pollutant/MWh) (Table G-3).

E = electricity consumption of an electric fireplace (270.84 kWh/fireplace/yr) (Sacramento Metropolitan Air Quality Management District 2021).

UC_1 = unit conversion from kWh to MWh (0.001 MWh/kWh).

UC_2 = unit conversion from lb to MT (0.00045359290943564 MT/lb).

GPF = number of electric fireplaces in the project.

The average electricity consumption of an electric fireplace was derived assuming that 56 percent of electric fireplaces are for aesthetics and consume 235 kWh per year while the remaining 44 percent of electric fireplaces are for heating and consume 299 kWh per year (Sac Metro AQMD 2021). There are no direct criteria pollutant emissions associated with electric fireplaces.

5.2.2 Consumer Products Screen

Consumer products are chemically formulated products used by household and institutional consumers, including degreasers; fertilizers/pesticides; detergents; cleaning compounds; polishes; floor finishes; cosmetics; personal care products; home, lawn, and garden products; disinfectants; sanitizers; aerosol paints; and automotive specialty products. Consumer products do not include other paint products, furniture coatings, or architectural coatings.

CalEEMod calculates the fugitive VOC emissions from three types of consumer products: general category, pesticides/fertilizers, and parking degreasers. The emission calculation variables for each consumer product type differs slightly based on the land use subtypes.

The generic equation for fugitive VOC emissions from consumer products is as follows.

$$E = EF \times A$$

Where:

E = consumer products emissions (lb VOC/day).

EF = consumer products emission factor (lb VOC/sqft/day).

A = consumer product use area (sqft).

For general category consumer products, the emission factor is 2.14×10^{-5} lb/sqft/day for projects located outside of the South Coast AQMD boundary and is 1.98×10^{-5} lb/sqft/day for projects located within the South Coast AQMD boundary. For pesticides/fertilizers the emission factor is 7.86×10^{-8} lb/sqft/day, and for parking degreasers it is 5.68×10^{-7} lb/sqft/day. See Appendix D, *Technical Source Documentation for Emissions Calculations*, for derivation of all consumer product type emission factors.

The general category emission calculation does not apply to Parking land use types. For all land use subtypes other than City Park, Golf Course, and Recreational Swimming Pool, the consumer product use area for the general category emission calculation is the building square footage value from the **Land Use** screen. If the land use subtype is either City Park, Golf Course, or Recreational Swimming Pool, the consumer product area is the recreational building square footage value.

The pesticide/fertilizer emission calculation only applies if the land use subtype is City Park or Golf Course. The consumer product use area is equal to the landscape area.

The parking degreaser emission calculation only applies if the land use type is Parking. The consumer product use area is equal to the lot acreage (converted to square feet).

5.2.3 Architectural Coatings Screen

VOC off-gassing emissions result from evaporation of solvents contained in surface coatings such as in paints and primers. The program calculates the VOC evaporative emissions from application of residential and non-residential surface coatings using the following equation, which is slightly different than the VOC evaporative emissions from coatings applied during construction (Section 4.8¸ *Architectural Coatings Screen*).

$$E_{AC} = EF_{AC} \times F \times A \times R$$

Where:

E_{AC} = architectural coating emissions (lb VOC/day).

EF_{AC} = architectural coating emission factor (lb VOC/sqft).

F = fraction of surface area coated (%). For all land use types except Parking, the default values are 25% for the exterior surface and 75% for the interior, which are based on an analysis conducted by South Coast AQMD. The fractions for the Parking land use type are 90% for interior surfaces and 10% for the exterior shell.

A = building surface area (sqft). The program assumes the total surface area for painting equals 2.7 times the building square footage for the residential land uses;2.0 times the building square footage for non-residential land use; 2.0 times the recreational building square footage for City Park, Golf Course, and Recreational Swimming Pool land use subtypes; and 0.05 times the lot acreage (converted to square feet) for the Parking land use type (South Coast AQMD 1993:Table A9-13-C). All land use information provided by a metric other than square footage (e.g., gasoline station pumps) will be converted to square footage using the default conversions or user-defined equivalence.

R = rate at which surfaces are repainted (%). All buildings are assumed to be repainted at a rate of 10% of area per year based on the assumptions used by South Coast AQMD.

The emission factor is based on the VOC content of the surface coatings and is calculated by using the following equation.

$$EF_{AC} = C_{VOC} \times UC_1 \times UC_2 \div C$$

Where:

EF_{AC} = architectural coating emission factor (lb VOC/sqft).

C_{VOC} = VOC content (g/L). This typically varies by air district and year (Table G-17).

UC_1 = unit conversion from lb to grams (0.00220462262 lb/g).

UC_2= unit conversion from L to gal (3.78541 L/gal).

C = coverage of one gal of surface coatings (180 sqft/gal).

CalEEMod also calculates the VOC emissions from the painting of stripes, handicap symbols, directional arrows, and car space descriptions in parking lots. See Appendix D, *Technical Source Documentation for Emissions Calculations*, for the studies conducted to determine a default percent of parking lot square footage that is painted. The equation for estimating striping emissions is the same as the equation for E_{AC} above, except that A is calculated using the following equation.

$$A = A_{PL} \times P$$

Where:

A_{PL} = parking lot area (sqft).

P = percent of parking lot area that is painted (6%).

The VOC content limit for parking area coatings is either provided by local air districts or based on the exterior coating VOC limit of the area where the project is located.

5.2.4 Landscape Equipment Screen

Landscape maintenance includes fuel combustion emissions from equipment such as lawn mowers, shredders/grinders, and leaf blowers. Projects located in colder climates may also generate landscape-related emissions during the winter months from snow removal equipment. CalEEMod can generate landscaping emissions based on statewide average equipment emission intensities for the number of snow and summer days for the project location. Alternatively, the user may input operating assumptions for individual landscaping equipment that will be required for the project.

5.2.4.1 Emissions from Statewide Defaults

Default statewide emission rates from landscaping equipment were developed using CARB's Small Off-Road Engines Model v1.1 (SORE2020) (CARB 2020b) (refer to Table G-24). The model was used along with the total building square footage and DUs in California to determine two emission factors (CEC 2020; California Department of Finance 2020). The emissions factor for commercial landscape equipment is in g/sqft of non-residential building space per day. The emissions factor for residential landscape equipment is in grams per DU per day. CalEEMod multiplies these emission factors by the number of summer days or winter days for the project location, which are assumed to represent the number of equipment operational days (refer to Table G-25). For some regions that do not have snow during winter, the number of actual days for the purpose of calculating landscaping emissions is typical of summer weather, at either 330 or 365 days per year (e.g., South Coast, Sacramento, San Joaquin Valley) unless specified by the local air district. However, regardless of the location, CalEEMod applies a default of 250 days per year for non-residential (e.g., commercial land uses) landscaping equipment because they would likely only operate during weekdays.

5.2.4.2 Emissions from User-Defined Equipment Inputs

A user who has a project-specific landscaping equipment inventory may estimate emissions by manually inputting equipment operating assumptions. CalEEMod calculates the exhaust emissions (running, starting, and evaporative) based on CARB's OFFROAD2017 methodology using the equation presented in Section 4.2, *Off-Road Equipment Screen*. The user must enter the number of pieces of equipment, fuel type, and hours of operation for each selected equipment type. Defaults are available for equipment horsepower and load factor. The following sections describe the development methodology for the equipment emission factors, default average horsepower, and load factor.

5.2.4.2.1 Emission Factor

Landscaping equipment (e.g., chainsaws, leaf blowers/vacuums, trimmers/edgers/brush cutters) emission factors are estimated using the Small Off-Road Engines Model v1.1 (SORE2020) (CARB 2020c) (refer to Table G-26). SORE2020 was run for an annual time period for all California counties for 41 scenario years (2010–2050). Emission factors for each equipment type and horsepower range combination were estimated based on daily exhaust and evaporative emissions and activity according to the following formula.

$$EF_p = \frac{E_p \times UC_1 \times UC_2}{Pop \times hp \times Activity \times LF}$$

Where:

EF = emission factor (g/bhp-hr) (Table G-26).

E = total exhaust or evaporative emissions (short tons/day).

UC_1 = unit conversion from daily emissions to annual emissions (365 days/year).

UC_2 = unit conversion from short tons to grams (90,7184.740760757 g/short ton).

Pop = total annual equipment population (number).

hp = average off-road equipment horsepower (unitless) (Table G-27).

$Activity$ = total annual usage of the off-road equipment (hrs/yr).

LF = load factor of the off-road equipment (unitless) (Table G-27).

p = pollutant.

Total daily exhaust emissions, total daily evaporative emissions, and population are outputs from SORE2020. The average horsepower, load factor, and annual operating hours estimates were obtained from SORE2020 model input files. SORE2020 emissions output includes sector-level detail, i.e., Commercial, Residential, Vendor, and Unknown. The “Commercial” sector includes all businesses that operate lawn and garden equipment except for licensed and unlicensed landscaping businesses which are included in the “Vendor” sector (CARB 2020a). Emission factors for commercial lawn and garden equipment are based on combined data for “Commercial” and “Vendor” sectors. Additionally, for gasoline powered equipment, SORE2020 output includes emissions for two engine types, (1) carburetor engines, and (2) fuel injection engines. Emission factors were aggregated over the engine type (i.e., carburetor and fuel injection) to develop 2-stroke gasoline (G2) and 4-stroke gasoline (G4) data for each equipment type and horsepower range. Similar to OFFROAD2017, the SORE2020 does not output emissions for CH_4 or N_2O. Emission factors for these pollutants were estimated based on the mass emission ratio method described above in Section 4.3, *Off-Road Equipment Emission Factors Screen*.

5.2.4.2.2 Average Horsepower and Load Factor

Average equipment horsepower default data are based on the most populous horsepower bin for each equipment and fuel type combination in SORE2020. Note that these defaults are different than the SORE2020 horsepower assumptions used in emission factors calculations. Default load factor data are also from SORE2020. Load factor is the ratio of the actual average power output to maximum power output of a piece of equipment. Load factors do not vary by horsepower range. Refer to Table G-27.

5.3 Energy Use Submodule

5.3.1 Energy Use Screen

Criteria pollutants and GHGs are emitted as a result of activities in buildings that consume energy in the form of natural gas and electricity.

Combustion of any type of fuel, including natural gas, emits criteria pollutants and GHGs directly into the atmosphere. When this occurs within buildings, it is considered a direct emission source associated with that building, and the program will calculate emissions of all criteria pollutants and GHGs accordingly. Fuel oil, kerosene, and liquefied petroleum gas can also be used as fuel in buildings but are not widely used in California compared to natural gas. As such, CalEEMod does not calculate emissions from combustion of these fuels within buildings. Emissions from wood combustion in wood burning stoves and fireplaces are calculated in the **Area Sources Submodule** (see Section 5.2.1, *Hearths Screen*).

Criteria pollutants and GHGs are also emitted during the generation of electricity at fossil fuel power plants. When electricity is used in buildings, the electricity generation typically takes place offsite at power plants, the majority of which burn fossil fuels. Because power plants are existing stationary sources permitted by air districts and/or the USEPA, criteria pollutant emissions are generally associated with the power plants themselves, and not individual buildings or electricity users. Additionally, criteria pollutant emissions from power plants are subject to local, state, and federal control measures, which can be considered the maximum feasible level of mitigation for stack emissions.

In contrast, GHG emissions from power plants are not subject to stationary source permitting requirements to the same degree as criteria pollutants. Likewise, it is difficult to mitigate GHG emissions emitted at power plants using exhaust after treatment control technologies. The most effective way to control GHGs from power plants is to reduce electricity demand. As such, GHGs emitted by power plants may be indirectly attributed to individual buildings and electricity users, who have the greatest ability to decrease usage by applying mitigation measures to individual electricity “end uses.” The program therefore calculates GHG emissions (but not criteria pollutant emissions) from regional power plants associated with building electricity use.

CalEEMod generates default electricity and natural gas consumption based on the Electricity Demand Forecast Zone (EDFZ) input in the **Project Detail** screen and the land use subtypes and building sqft input in the **Land Use** module. From these inputs, the default electricity and natural gas consumption is then provided to the user based on 2019 consumption estimates from the CEC’s (2020, 2021) 2018–2030 Uncalibrated Commercial Sector Forecast (Commercial Forecast) and the RASS (refer to Table G-28).

Within Title 24 of the California Code of Regulations (Building Standards Code) is Part 6, the Building Energy Efficiency Standards (Energy Code). CEC implements Title 24, Part 6 in order to increase the energy efficiency of newly constructed and altered residential and nonresidential buildings. The CEC adopted the Energy Code in 1978 and has since updated it numerous times over the years, increasing the energy efficiency of new buildings with each subsequent update. The latest Energy Code is for 2019. CEC adopted the 2022 Energy Code in August 2021, and it will take effect January 1, 2023 (CEC 2022).

The following sections summarize the data and assumptions made by CalEEMod to quantify default energy use and associated emissions.

5.3.1.1 Non-Residential Building Energy Use

CalEEMod uses the CEC’s Commercial Forecast database to develop energy intensity values (electricity and natural gas usage per sqft/yr) for non-residential buildings (CEC 2021). The database lists energy use intensity by building type, end use category, and EDFZ. Appendix D, *Technical Source Documentation for Emissions Calculations,* describes in detail the method used to analyze the Commercial Forecast data.

5.3.1.2 Residential Building Energy Use

CalEEMod uses data collected during the RASS to develop energy intensity values (electricity and natural gas usage per DU per year) for residential buildings. Similar to the Commercial

Forecast, the RASS dataset lists energy use intensity by building type, end use category, and EDFZ. Appendix D, *Technical Source Documentation for Emissions Calculations,* describes in detail the method used to analyze the RASS data.

5.3.1.3 Parking Lot Energy Use

For parking lots, several studies have been published regarding the energy use from lighting, ventilation and elevators in parking lots and structures. This data has been incorporated into CalEEMod to calculate electricity use, based on parking lot land use subtype. Appendix D, *Technical Source Documentation for Emissions Calculations,* contains further information regarding the assessment of the electricity usage by parking lots and structures, as well as guidance for overriding the default values (e.g., if the number of elevators is known).

5.3.1.4 Energy Use from Other Land Uses

There are a few CalEEMod land use categories that are not included in the Commercial Forecast or RASS data. These include Golf Courses, Parks, and Recreational Pools. These currently do not have associated default energy use values within the program; however, the user may enter non-default values estimated outside of the program.

5.3.1.5 Calculation of Emissions from Energy Use

CalEEMod calculates emissions associated with buildings by multiplying the natural gas use by appropriate natural gas emission factors and by multiplying electricity use by the GHG intensity factors of the electric utility selected on the **Utility Information** screen (refer to Table G-3). As previously discussed, natural gas use will contribute to both criteria and GHG emissions. See Table G-4 for natural gas emission factors used by CalEEMod. Electricity use will contribute to GHG emissions only.

Emissions from natural gas and electricity use are calculated by the program for each land use using the following equations.

$$\text{Natural Gas Emissions}_i = \Sigma_j(\text{EF}_i \times \text{Energy Intensity} \times \text{Size})$$

Where:

Natural Gas Emissions = natural gas emissions (lb/yr).

EF = emission factor (lb/KBTU) (Table G-4).

Energy Intensity = natural gas energy intensity for a land use (KBTU/sqft/yr or KBTU/DU/yr).

Size = size metric (sqft or DU).

i = each criteria and GHG pollutant.

j = land use type.

$$\text{Electricity Emissions}_i = \Sigma_i(\text{EF}_i \times \text{Energy Intensity} \times \text{Size} \times \text{UC})$$

Where:

Electricity Emissions = electricity emissions (lb/yr).

EF = utility emission factor (lb CO_2e/MWh) (Table G-3).

Energy Intensity = electricity energy intensity for a land use (kWh/sqft/yr or kWh/DU/yr).

Size = size metric (sqft or DU).

UC = unit conversion from kWh to MWh (0.001 MWh/kWh).

i = each GHG pollutant.

i = land use type.

5.4 Water and Wastewater Submodule

5.4.1 Water and Wastewater Screen

5.4.1.1 Inputs and Defaults

Water used and wastewater generated by land use development projects results in indirect GHG emissions from the energy used to supply, distribute, and treat the water and wastewater. The wastewater treatment process can also directly emit both CH_4 and N_2O, as discussed in Section 5.4.1.55, *Wastewater Volume by Treatment Method*. The **Water and Wastewater** screen displays the following key data fields for the quantification of emissions.

- Annual outdoor and indoor water use for the project.
- Water energy-intensity factors for the supply, distribution, and treatment of water and wastewater.
- Percentage of wastewater by treatment method (e.g., septic).

Data, assumptions, and equations used to generate defaults for each of these variables are further described in the following sections.

5.4.1.2 Annual Outdoor Water Use

CalEEMod calculates outdoor water consumption using the Maximum Applied Water Allowance (MAWA) method established under the California Department of Water Resources' (DWR) 2015 Model Water Efficient Landscape Ordinance (MWELO) (California Code of Regulations [C.C.R.], Title 23, Division 2, Chapter 2.7). The MAWA is the upper limit of the annual allowed water use for a landscaped area. The calculation is based on the size of the landscape area and expected evapotranspiration. The MAWA equation is as follows.

$$\text{MAWA} = [(\text{ET}_{\text{O}} - \text{E}_{\text{ppt}}) \times \text{UC}_1] \times [(\text{AF}_{\text{ETo}} \times \text{LA}) + (1 - \text{AF}_{\text{ETo}}) \times \text{SLA}]$$

Where:

MAWA = annual outdoor water use for the land use subtype (gal/yr).

ET_O = evapotranspiration rate (in/year). CalEEMod determines the evapotranspiration rate based on the project location and Appendix A of the MWELO (23 C.C.R. Appendix A) (refer to Table G-29).

E_{ppt} = effective precipitation, which is 25% of total annual precipitation (inches/year). CalEEMod determines total annual precipitation based on the project location, user selected analysis scale (e.g., county, air basin), and data from NOAA (2021a) (refer to Table G-29). The user may elect to exclude precipitation from the calculation of outdoor water use by selecting “No” in the “Include Precipitation?” column. Excluding the precipitation adjustment will increase the calculated annual water consumption rate for the project.

UC_1 = unit conversion from acre-inches/acre to gal/sqft (0.62 gal per sqft per acre-inch per acre).

AF_{ETo} = Evapotranspiration adjustment factor for maximum allowable water use, pursuant to Senate Bill X7-7. The factor is 0.55 for residential development constructed after 2015 and 0.45 for non-residential development. The factors are fixed regardless of the operational year. Further strengthening of regulation may lower maximum allowable water use. Accordingly, projected outdoor water use for projects operating in future years is likely conservative.

LA = landscape area of the land use subtype (sqft). The landscape area is either auto-calculated by CalEEMod or input by the user in the **Land Use** module. As discussed in Section 3.1, *Land Use Screen*, landscape area includes water features and all planting and turf areas in a landscape design plan, including special landscape area.

SLA = special landscape area of the land use subtype (sqft). The special landscape area must be provided by the user in the **Land Use** module, as discussed in Chapter 3, *Land Use Module*.

Note that landscape area is a required input to the outdoor water consumption equation. As discussed in Chapter 3, *Land Use Module*, defaults for the landscape area are only available for the single-family housing land use subtype. The user must provide the landscaping area for all other land use subtypes. Failure to define the landscaping area in the **Land Use** module will result in 0 outdoor water consumption unless the user specifies a non-zero value for the special landscape area. If your project includes outdoor water consumption and the default value shown in the “Outdoor Water Use” column is 0, return to the **Land Use** module and confirm the landscape area has been defined for all land use subtypes, as applicable.

Some land use types may include special landscape area. This area includes the portion of landscape dedicated solely to edible plants, areas irrigated with recycled water, water features using recycled water, and area dedicated to active play, such as parks, sports fields, golf courses, and where turf provides a playing surface. As discussed in Chapter 3, *Land Use Module*, CalEEMod assumes 0 special landscape area as a default for all land use subtypes except city park, golf course, elementary school, high school, junior college (2 yr), junior high school, university/college (4 yr). For these uses, the default special landscape area is equal to the landscape area (i.e., the model assumes 100 percent of the landscape area is classified as special landscape area).

5.4.1.3 Annual Indoor Water Use

CalEEMod calculates indoor residential water consumption based on per capita daily water use rates from the *Residential End Uses of Water* published by the Water Research Foundation (WRF) (2016) (refer to Table G-30). The equation follows.

$$\text{Indoor}_{\text{residential}} = \text{GCPD} \times \text{Pop} \times \text{UC}_1 \times \text{DU}$$

Where:

$Indoor_{residential}$ = annual indoor water use for residential land use types (gal/yr).

$GCPD$ = indoor residential water consumption rate (34.5 gal per person per day). The water use rate is from the WRF (2016). The value is fixed regardless of the operational year. Water use rates may decline in the future due to technological improvements, more stringent regulation, and/or increasing awareness of resource conservation. Accordingly, projected residential indoor water use for projects operating after 2018 is likely overestimated.

Pop = persons per dwelling unit (person/unit) (California Department of Finance 2020).

UC_1 = unit conversion from daily to annual (365 days/yr).

DU = dwelling units of residential land use subtype input by the user in the **Land Use** module.

CalEEMod calculates indoor water consumption for most non-residential subtypes using data from the year 2000 from the Pacific Institute’s *Waste Not Want Not* (Gleick et al. 2003). Total gal (indoor and outdoor) of water used per day per metric are reported in Appendices E and F of the Pacific Institute report, where the metric is employee, student, room, acre, or sqft, depending on the land use. For example, water use at office and retail land uses is reported in a metric of gal per employee per day, while water use at hotels and motels is reported in a metric of gal per room per day. For industrial land use categories, the default indoor water use rate was calculated by dividing the annual water use in California industry by the industrial work area in California (see Appendix D8, *Default Water Use for Industrial Land Uses*). CalEEMod converts the daily water use to annual water use based on the number of days of operation for that land use. CalEEMod assumes that schools operate for 180 days per year while all other non-residential land uses operate for 225 days per year (excluding weekends and holidays). The figures in Appendices E and F of the Pacific Institute report shows the percent of outdoor water use; this percent was removed from total water use to obtain indoor water consumption (gal per year).[13]

For a few land uses (library, place of worship, movie theater, arena, and civic center), the Pacific Institute report does not provide sufficient data to develop indoor water consumption defaults. For these land use subtypes, CalEEMod uses data from the American Water Works Association (AWWA) Research Foundation’s *Commercial and Institutional End Uses of Water* (Dziegielewski et al. 2000). The report includes total gal of water used per employee per day, based on surveys of Southern California businesses.

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[13] As discussed above, CalEEMod calculates default outdoor water consumption for non-residential land use types using the MWELO method. However, calculated default outdoor water consumption is not used in this calculation of indoor water consumption. This is because the total water consumption data from the Pacific Institute are based on data for the year 2000, which predates the 2015 MWELO. Subtracting outdoor water use that was calculated per the 2015 MWELO from a total water consumption estimate based on year 2000 data is likely to overestimate the fraction of indoor water consumption.

Defaults generated for non-residential indoor water consumption are limited and conservative for the following reasons. The user should replace these defaults with project-specific data whenever possible (refer to Table G-31).

- The consumption defaults are based on historical data for the year 2000, as reported by the Pacific Institute (Gleick et al. 2003) and AWWA's Research Foundation (Dziegielewski et al. 2000). The default values are fixed regardless of the operational year. Indoor water use rates have declined since 2000 and may continue to decline in the future due to technological improvements, more stringent regulation, and/or increasing awareness of resource conservation. Accordingly, the default values likely overestimate actual non-residential indoor water use for development constructed between 2010 and 2050 (the available operational analyses years in CalEEMod).
- The consumption defaults for all non-residential land use subtypes except library, place of worship, movie theater, arena, and civic center are based on statewide average data and do not consider geographical differences in water use patterns.
- The consumption defaults for the library, place of worship, movie theater, arena, and civic center land use subtypes are based on surveys of Southern California businesses. The defaults are applied to all projects with these land use subtypes, regardless of project location.

5.4.1.4 Water Energy-Intensity Factors

The default water energy-intensity factors are based on a study published by the Pacific Institute (Sziniai et al. 2021) (refer to Table G-32). The factors are reported in units of kWh per million gallons (MG) of water used, and represent the amount of electricity needed to: (1) supply and convey the water from the source, (2) treat the water to usable standards, and (3) distribute the water to individual the user. The sum of these factors gives the total electricity required to supply, treat, and distribute water for outdoor uses. For indoor uses, the electricity needed to process the resulting wastewater is also included.

The default water energy-intensity factors are mapped to DWR's (2021) 10 hydrologic regions. CalEEMod selects the appropriate regional factors based on the project location (refer to Table G-33).

5.4.1.5 Wastewater Volume by Treatment Method

When a development project generates wastewater, the water is typically either treated onsite in septic tanks or sent to a centralized wastewater treatment plant to be treated by one of several possible methods. Anaerobic decomposition in septic tanks produces fugitive emissions of CH_4.

Treatment methods at centralized wastewater treatment plants may be composed of aerobic processes or facultative lagoons. The solids from these treatment methods can be digested anaerobically to produce digester gas. In some cases, the combusted digester gas may be part of a cogeneration system that recovers the heat generated from combustion and generates electricity, which can be used for on-site processes.

Anaerobic decomposition in septic tanks and facultative lagoons can produce fugitive emissions of methane. The following figure provides an example of the process flow for a centralized wastewater treatment facility that treats the sewage aerobically, produces digester gas in anaerobic digesters, and combusts the gas. Figure C-3 shows where the GHG emissions are occurring in the process for aerobic systems.

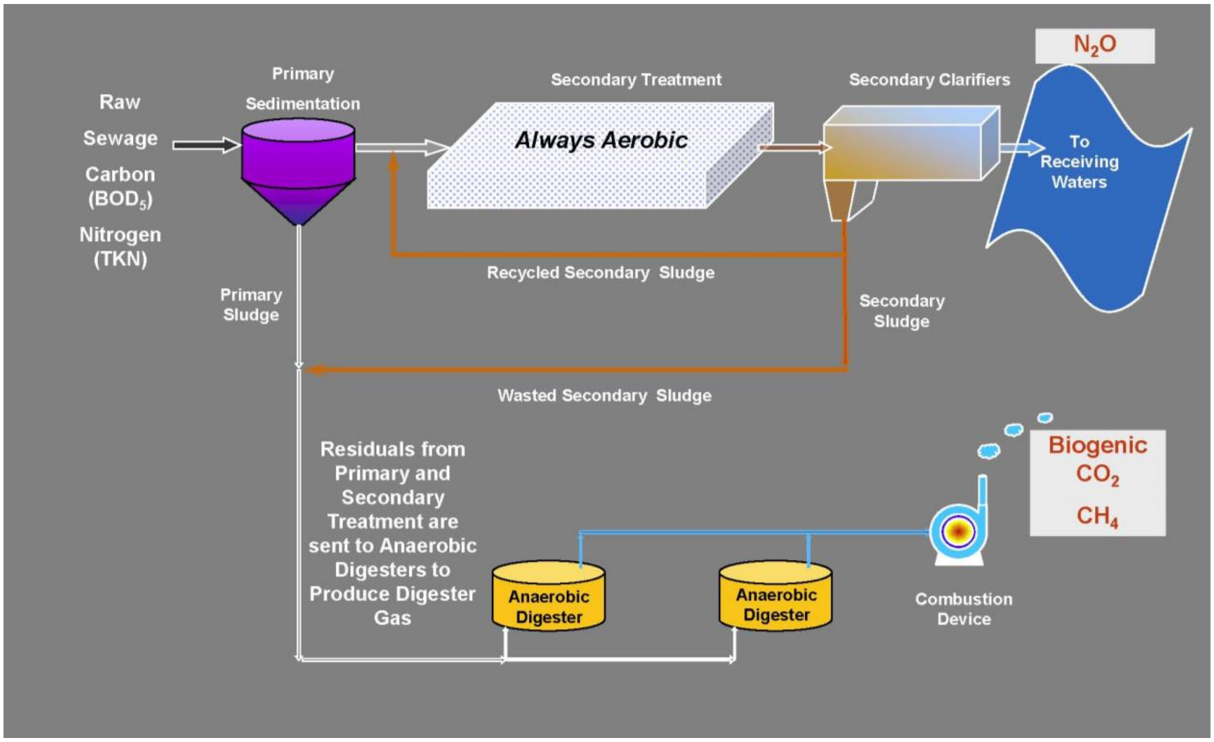

Figure C-3. Centralized Treatment Flow Schematic for Aerobic Systems

As shown in the figure above, N_2O is produced when treated wastewater is released as effluent into aquatic environments such as rivers and estuaries. Although the nitrification/denitrification processes within the wastewater treatment plant may also produce N_2O, the USEPA (2008:8-7) estimated that this contributed to less than 3 percent of national N_2O emissions associated with wastewater in 2005. Therefore, the program assumes that all N_2O emissions are generated from effluent discharged into aquatic environments.

CO_2 emissions are generated from both aerobic and anaerobic processes, as well as from the combustion of digester gas, but CalEEMod currently only calculates combustion emissions. When digester gas is combusted to generate electricity, fossil fuel emissions are offset by this renewable power generation. By default, CalEEMod assumes no cogeneration; however, the user can input an estimate of the percentage of the digester gas combusted. For aerobic and facultative lagoon wastewater treatment, digestion (listed in the last two columns on the **Water and Wastewater** screen) should equal 100 percent. For septic systems, the digestion could be 0 percent or 100 percent. CalEEMod will debit the biogenic combustion CO_2 with the CO_2 that would otherwise have been sourced from fossil fuel combustion.

Centralized wastewater treatment facilities may also treat wastewater using facultative lagoons. The following figure is an example of the treatment process if facultative lagoons provide the secondary treatment assuming process solids are sent to anaerobic digesters and the digester gas is combusted. Figure C-4 shows where the GHG emissions are occurring in the process for facultative lagoons.

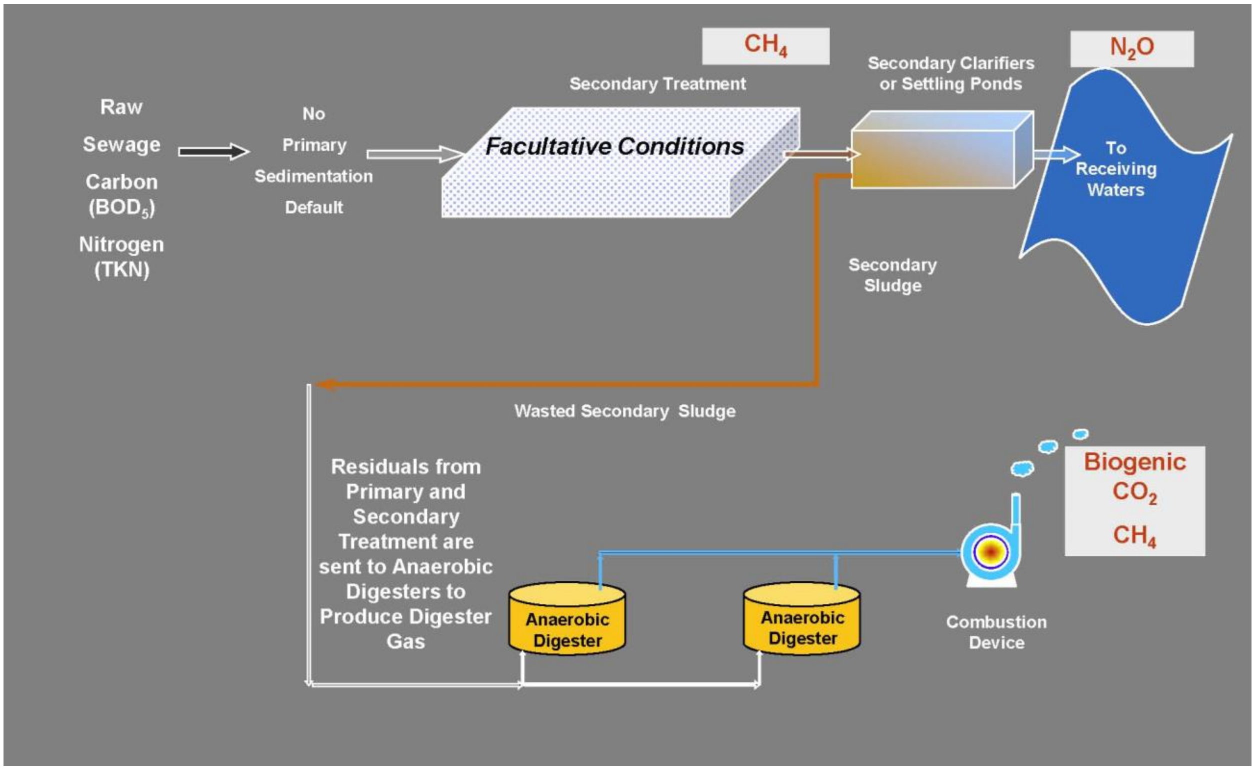

Figure C-4. Centralized Treatment Flow Schematic for Facultative Lagoons

CalEEMod calculates the volume of project-generated wastewater treated by method based on the region-specific distribution of wastewater treatment methods (expressed as the percentage of wastewater treatment by method) (refer to Table G-34). Where region-specific data are not available, the model applies statewide default percentages shown in Table C-10 based on CARB's GHG emission inventory. The user can replace the treatment defaults with project-specific percentages, but the total percentage must equal 100 percent.

Table C-10. Statewide Default Treatment Distribution

Septic (%)	Aerobic (%)	Facultative Lagoons (%)
10.33	87.46	2.21

5.4.1.6 Calculation of GHG Emissions from Water Use

CalEEMod calculates CO_2, CH_4, and N_2O emissions from indoor water use according to the following equation.

$$E_p = V_{indoor} \times E_{indoor} \times EF_P \times UC_1$$

Where:

E = emissions from indoor water use (MT/yr).

V_{indoor} = volume of indoor water use (MG/yr). See Section 5.4.1.23, *Annual Indoor Water Use*.

E_{indoor} = electricity required to supply, treat, and distribute water and the resulting wastewater (kWh/MG) (Table G-32). See Section 5.4.1.44, *Water Energy-Intensity Factors*.

EF = carbon intensity of electricity provider (lb/MWh) (Table G-3). CalEEMod determines the electric utility company for the project based on the project location. The default electricity provider and carbon intensities are shown in the **Utility Information** screen, as discussed in Section 2.2, *Utility Information Screen*.

UC_1 = unit conversion from kWh to MWh (0.001 MWh/kWh).

p = pollutant (CO_2, CH_4, or N_2O).

CalEEMod calculates CO_2, CH_4, and N_2O emissions from outdoor water use according to the following equation.

$$E_p = V_{outdoor} \times E_{outdoor} \times EF_P \times UC_1$$

Where:

E = emissions from outdoor water use (MT/yr).

$V_{outdoor}$ = volume of outdoor water use (MG/yr). See Section 5.4.1.2, *Annual Outdoor Water Use*.

$E_{outdoor}$ = electricity required to supply, treat, and distribute water (kWh/MG) (Table G-32). See Section 5.4.1.44, *Water Energy-Intensity Factors*.

EF = carbon intensity of electricity provider (lb/MWh) (Table G-3). CalEEMod determines the electric utility company for the project based on the project location. The default electricity provider and carbon intensities are shown on the **Utility Information** screen, as discussed in Section 2.2, *Utility Information Screen*.

UC_1 = unit conversion from kWh to MWh (0.001 MWh/kWh).

p = pollutant (CO_2, CH_4, or N_2O).

The sum of emissions from indoor and outdoor water uses for each land use type gives the total GHG emissions from project water consumption.

5.4.1.7 Calculation of GHG Emissions from Wastewater Treatment

GHG emissions generated by wastewater treatment are calculated according to the following equation.

$$E_p = \sum_{t} V \times UC \times EF_P$$

Where:

E = emission from wastewater treatment (MT/yr).

V = volume of wastewater by treatment method (gal/yr). See Section 5.4.1.55, *Wastewater Volume by Treatment Method*.

UC = unit conversion from short tons to MT (0.907185 MT/short ton).

EF = emission factor for treatment process (short ton/gal/yr) (Table G-35) (see below).

p = pollutant (CO_2, CH_4, or N_2O).

t = treatment process.

The emission factors for each type of wastewater treatment are calculated using CARB's (2010) *Local Government Operations Protocol* (LGOP), which is consistent with USEPA methodologies for the national GHG inventory. The assumptions and equations used to calculate the emission factors are summarized below.

5.4.1.7.1 Methane Emission Factor for Septic Systems

Septic systems utilize microbes to decompose wastewater anaerobically. A by-product of this anaerobic decomposition is CH_4, which is quantified using Equation 10.5 from the LGOP, as follows.

$$EF_{septic} = V \times BOD_5 \times UC_1 \times BO \times MCF_{septic} \times UC_2 \times UC_3$$

Where:

EF_{septic} = fugitive CH_4 emission factor for septic systems (short ton CH_4/gal/yr) (Table G-35).

V = volume of wastewater (L/yr).

BOD_5 = amount of BOD_5 produced per day (200 mg/L). BOD is the "biological oxygen demand," which measures the degradable organic component of the wastewater that could deplete dissolved oxygen in receiving waters if left untreated. BOD_5 is the measurement of dissolved oxygen depletion from a liquid sample held for a 5-day test. The 200 mg per L of wastewater default is typical for residential and commercial wastewater. A higher value is typically associated with certain types of industrial wastewater.

UC_1 = unit conversion from mg to kg (10^{-6} kg/mg).

BO = maximum CH_4-producing capacity for domestic wastewater (0.6 kg CH_4/kg BOD_5 removed).

MCF_{septic} = CH_4 correction factor for septic systems (0.5).

UC_2 = unit conversion from kg to short tons (1.10^{-3} short ton/kg).

UC_3 = unit conversion from L to gal (3.78541 L/gal).

5.4.1.7.2 Methane Emission Factor for Facultative Lagoons

The CH_4 emissions factor for wastewater treatment through facultative lagoons is calculated using Equation 10.3 from LGOP, as follows.

$$EF_{lagoon} = V \times BOD_5 \times UC_1 \times (1 - F_P) \times BO \times MCF_{anaerobic} \times F_{removed} \times UC_2 \times UC_3$$

Where:

EF_{lagoon} = fugitive CH_4 emission factor for facultative lagoons (short ton CH_4/gal/yr) (Table G-35).

V = volume of wastewater (L/yr).

BOD_5 = amount of BOD_5 produced per day (200 mg/L).

UC_1 = unit conversion from mg to kg (10^{-6} kg/mg).

F_P = fraction of BOD_5 removed in primary treatment (0). CalEEMod assumes no primary treatment.

BO = maximum CH_4-producing capacity for domestic wastewater (0.6 kg CH_4 / kg BOD_5 removed).

$MCF_{anaerobic}$ = CH_4 correction factor for anaerobic systems (0.8).

$F_{removed}$ = fraction of overall lagoon BOD_5 removal performance (1).

UC_2 = unit conversion from kg to short tons (1.10^{-3} short ton/kg).

UC_3 = unit conversion from L to gal (3.78541 L/gal).

5.4.1.7.3 Methane Emission Factor for Combustion of Digestion Gas

Anaerobic digesters produce CH_4-rich biogas, which is typically combusted on site. In some cases, the biogas is combusted simply for the purpose of converting CH_4 to CO_2. In other cases, a cogeneration system is used to harvest the heat from combustion and use it to generate electricity for on-site energy needs (discussed further below). In either case, inherent inefficiencies in the system result in incomplete combustion of the biogas, which results in remaining CH_4 emissions. The CH_4 emissions factor from incomplete combustion of digester gas is quantified using Equation 10.1 from LGOP, as follows.

$$EF_{digester} = V \times DG \times F_{CH4} \times P_{CH4} \times (1 - DE) \times UC_1 \times UC_2 \times UC_3$$

Where:

$EF_{digester}$ = CH_4 emission factor for incomplete combustion (short ton CH_4/gal/yr) (Table G-35).

V = volume of wastewater (gal/yr).

DG = volume of biogas generated per volume of wastewater treated (0.01 ft^3 biogas/gal). USEPA (2008:8-9) estimates 1.0 ft^3 of digester gas per person per day and 100 gal of wastewater per person per day.

F_{CH4} = fraction of CH_4 in biogas (0.65) (USEPA 2008:8-9).

P_{CH4} = density of CH_4 at standard conditions (662 g/m^3).

DE = CH_4 destruction efficiency (0.99).

$MCF_{anaerobic}$ = CH_4 correction factor for anaerobic systems (0.8).

UC_1 = unit conversion from ft^3 to m^3 (0.0283 m^3/ft^3).

UC_2 = unit conversion from kg to short tons (1.10^{-3} short ton/kg).

UC_3 = unit conversion from grams to kg (10^{-3} kg/g).

5.4.1.7.4 Biogenic CO_2 Emission Factor Combustion of Digestion Gas

The biogenic CO_2 emission factor for the combustion of biogas is calculated using the following equation.

$$EF_{biogenic} = V \times DG \times F_{CH4} \times EF \div UC_1$$

Where:

$EF_{biogenic}$ = CO_2 emission factor for biogas combustion (short ton CO_2/gal/yr) (Table G-35).

V = volume of wastewater (gal/yr).

DG = volume of biogas generated per volume of wastewater treated (0.01 ft^3 biogas/gal) (USEPA 2008:8-9).

F_{CH4} = fraction of CH_4 in biogas (0.65) (USEPA 2008:8-9).

EF = emission factor for CH_4 combustion (0.120 lb CO_2 / ft^3 CH_4) (United States Department of Energy 2005).

UC_1 = unit conversion from lb to short ton (0.0005 short ton/lb).

5.4.1.7.5 Electricity Factor for Cogeneration

The following equation derived from USEPA's (2006c) *Solid Waste Management and Greenhouse Gases* is used to calculate the amount of electricity generated from the combusted biogas.

$$E_{cogeneration} = V \times DG \times F_{CH4} \times HHV_{CH4} \times ECF \times EFF \times UC_1$$

Where:

$E_{cogeneration}$ = electricity generation factor for biogas combustion (MWh/gal/yr).

V = volume of wastewater (gal/yr).

DG = volume of biogas generated per volume of wastewater treated (0.01 ft^3 biogas/gal) (USEPA 2008:8-9).

F_{CH4} = fraction of CH_4 in biogas (0.65) (USEPA 2008:8-9).

HHV_{CH4} = heating value of methane (1,012 BTU / ft^3 CH_4).

ECF = energy conversion factor (0.00009 kWh/BTU).

EFF = efficiency Factor (0.85). USEPA (2006c) assumes a 15% system efficiency loss, to account for system down-time. USEPA assumes that methane is flared during down-time.

UC_1 = unit conversion from kWh to MWh (0.001 MWh/-kWh).

Since this amount of electricity is generated onsite and no longer needs to be supplied by the local electricity utility, the indirect CO_2e emissions associated with that utility electricity generation are also avoided. The avoided CO_2e emissions are calculated by multiplying the amount of electricity generated (in MWh) by the local utility carbon-intensity factor (Table G-3).

5.4.1.7.6 Nitrous Oxide Emission Factor

N_2O is produced when treated wastewater is discharged to aquatic environments such as rivers or estuaries. The remaining nitrogen in treated wastewater effluent is converted to N_2Oin a multi-step process accomplished by bacteria that are present in soil and aquatic environments. The N_2O emission factor is quantified using Equation 10.9 from the LGOP, as follows.

$$EF_{discharge} = V \times UC_1 \times N_{load} \times R \times EF \times UC_2 \times UC_3$$

Where:

$EF_{discharge}$ = N_2O emission factor for effluent discharge (short ton N_2O/gal/yr) (Table G-35).

V = volume of wastewater (L/yr).

UC_1 = unit conversion from mg to kg (10^{-6} kg/mg).

N_{load} = mass of nitrogen discharged per L of wastewater (26 mg N_2 /L) (USEPA 2013). This value is appropriate for residential and commercial wastewater. A higher value may be more appropriate for certain types of industrial wastewater.

R = ratio of molecular weights for N_2O and N_2 (44 g N_2O/28 g N_2) (USEPA 2008).

EF = N_2O effluent emission factor (0.005 kg N_2O/kg N).

UC_2 = unit conversion from kg to short tons (1.10^{-3} short ton/kg).

UC_3 = unit conversion from L to gal (3.78541 L/gal).

5.5 Solid Waste Submodule

5.5.1 Solid Waste Screen

Municipal solid waste (MSW) is the amount of material that is disposed of by land filling, recycling, or composting. CalEEMod calculates the indirect GHG emissions associated with waste that is disposed of at a landfill. The program uses annual waste disposal rates from the California Department of Resources Recycling and Recovery (CalRecycle) data for individual land use types (CalRecycle n.d.) (refer to Table G-36). If waste disposal information was not available, waste generation data was used. CalEEMod uses the overall California MSW composition to generate the necessary types of different waste disposed into landfills. The program quantifies the GHG emissions associated with the decomposition of the waste, which generates CO_2 and CH_4 based on the total amount of degradable organic carbon (DOC).[14]

The amount of carbon generated per short ton of waste is calculated according to the following equation.

$$G = \sum_{MSW} DOC \times DANF \times C \times A$$

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[14] Landfill gas generation is dependent upon the amount, type, age and moisture content of the disposed waste. USEPA has developed emission factors for landfill gas as specified in Section 2.4 of AP-42, which are incorporated in the LANDGEM model. This model uses a first order decay equation that will vary with time. However, there is no need to use a time-varying emissions model, as we are interested in total emissions of gases that could be emitted from a short ton of waste. Therefore, instead of using the LANDGEM model, the volume of landfill gas from solid waste will be based on the total amount of degradable organic carbon.

Where:

G = generation mass of carbon (short ton carbon per short ton of waste) (Table G-37).

DOC = degradable organic carbon fraction (%) (CARB 2010:Table 9.6).

DANF = degradable anaerobic fraction (%) (CARB 2010:Table 9.7).

C = waste stream composition (%) (California Integrated Waste Management Board 2020:Table 4).

A = anaerobic carbon fraction (0.5).

MSW = waste category (e.g., newspaper).

The amount of CH_4 and CO_2 emitted is calculated by assuming collection and destruction efficiencies. Regional defaults are available for the percent of project waste that is expected to be sent to landfills with a gas collection system. The default collection efficiency for these systems is 75 percent and the destruction efficiency is 98 percent. Oxidation of CH_4 and CO_2 is calculated according to the following equations.

$$E_{CH4} = T \times G \times [C \times (1 - D) + (1 - C) \times (1 - Ox)] \times R \times UC$$

$$E_{CO2} = T \times G \times [C \times D + (1 - C) \times Ox + 1] \times R \times UC$$

Where:

E_{CH4} = CH_4 emissions (MT CH_4/yr).

E_{CO2} = CO_2 (biogenic) emissions (MT CO_2/yr).

T = short tons of waste generated by the project (short ton/yr).

G = generation mass of carbon (short ton carbon per short ton of waste) (Table G-37).

C = collection efficiency of landfill gas (75%).

D = destruction efficiency of landfill gas (98%).

Ox = oxidation efficiency (10%).

R = ratio of molecular weights for CO_2 and carbon (44 g CO_2 / 12 g carbon) and CH_4 to carbon (16 g CH_4 / 12 g carbon).

UC = unit conversion from short tons to MT (0.907185 MT/short ton).

CalEEMod will also calculate the electricity from any combusted biogas that is used for cogeneration. If applicable, the user should specify the percent of landfill gas energy recovery in the Capture Gas Energy Recovery data field (CalEEMod defaults to 0 percent). Since this amount of electricity is generated on-site and no longer needs to be supplied by the local electricity utility, the indirect GHG emissions associated with that utility electricity generation are avoided. The avoided GHG emissions are calculated by multiplying the amount of electricity generated (in MWh) by the local utility carbon-intensity factor, according to the following equation. Please note that, depending on the amount of electricity generated and the carbon intensity of the electric utility, calculated emissions for the waste sector (or certain pollutants within the waste sector) may be negative. In this case, negative values indicate that displaced grid energy from cogeneration will offset emissions associated with landfill treatment of project-generated waste.

$$E_{cogeneration} = T \times L_r \times (C \times U) \times UC$$

Where:

$E_{cogeneration}$ = avoided GHG emissions from electricity generated from cogeneration (MT pollutant/year).

T = short tons of waste generated by the project (short ton/yr).

L_r = percent of project-generated waste that is sent to a landfill with cogeneration (%) (user input in the **Solid Waste** screen).

C = energy recovery of landfill gas (0.45 MWh/short ton waste) (USEPA 2016a:1-2; USEPA 2021:1).

U = carbon intensity of electric utility (lb CO_2e/MWh).

UC = unit conversion from lb to MT (0.00045359290943564 MT/lb).

5.6 Refrigerants Submodule

5.6.1 Refrigerants Screen

Refrigerants are substances used in equipment for air conditioning (A/C) and refrigeration. Most of the refrigerants used today are HFCs or blends thereof, which can have high GWP values. All equipment that uses refrigerants has a charge size (i.e., quantity of refrigerant the equipment contains), and an operational refrigerant leak rate, and each refrigerant has a GWP that is specific to that refrigerant. CalEEMod quantifies refrigerant emissions from leaks during regular operation and routine servicing over the equipment lifetime, and then derives average annual emissions from the lifetime estimate according to the following equation.

$$E = \sum_{I} (((CS \times OLR) + (CS \times SLR \times (TS \div L))) \times GWP)_r \times KSF \times UC_1$$

Where:

E = average annual refrigerant emissions (MT CO_2e/yr).

CS = equipment charge size (kg refrigerant/KSF). The equipment charge size is the total quantity of refrigerant installed in the refrigeration or A/C equipment. Default equipment charge sizes are based on industry data published by USEPA (2016b) (Table G-38).

OLR = annual operational leak rate (%) (USEPA 2016b) (Table G-38).

SLR = service leak rate (%) (USEPA 2016b) (Table G-38).

TS = times serviced (number of times serviced over equipment lifetime) (USEPA 2016b) (Table G-38).

L = average equipment operational lifetime (years) (USEPA 2016b) (Table G-38).

GWP = global warming potential (unitless) (IPCC 2007; CARB 2020d; World Meteorological Organization 2018) (Table G-39).

KSF = land use size (1,000 sqft). Emissions are quantified by land use subtype, with the input for the land use size based on information in the **Land Use** module.

UC_1 = unit conversion from kg to MT (0.001 MT/kg).

r = refrigerant.

I = equipment type.

Different types of refrigeration equipment are used by different types of land uses. For example, an office may use various types of A/C equipment, while a supermarket may use both A/C equipment and refrigeration equipment. Default refrigeration and A/C equipment types by land use subtype, as well as the default refrigerant used in each equipment type, are based on USEPA (2016b).

5.7 Off-Road Equipment Submodule

5.7.1 Off-Road Equipment Screen

The **Off-Road Equipment** screen calculates emissions from off-road equipment (e.g., forklifts, cranes, loaders, generator sets) used during project operation. The program allows the user to enter the number of pieces of equipment, fuel type, engine tier, daily hours of operation, annual days of operation, horsepower, and load factor. Defaults are available for horsepower and load factor, as described in Sections 4.2.1, *Average Horsepower*, and 4.2.2, *Load Factor* (refer to Table G-12). For each equipment type, the model automatically defaults to diesel fuel, average engine tier, 8 hours of daily operation, and 260 days of annual operation. The user can replace the defaults with project-specific data.

5.7.2 Off-Road Equipment Emission Factors Screen

Emissions are quantified according to the equation shown in Section 4.2, *Off-Road Equipment Screen*.

5.8 Stationary Sources Submodule

The **Stationary Source** submodule calculates emissions from emergency generators and fire pumps and process boilers.

5.8.1 Emergency Generators and Fire Pumps Screen

The user must enter the number of pieces of equipment, fuel type, and hours of operation for each selected equipment type. Defaults are available for equipment horsepower and load factor. Emissions for emergency generators and fire pumps are calculated using the following equation.

$$E_p = \sum_i (EF_i \times Pop_i \times hp_i \times Load_i \times Activity_i)$$

Where:

E = total daily generator and/or fire pump equipment emissions (g/day).

EF = emission factor in grams per horsepower-hour (g/bhp-hr) (see below) (Table G-40).

Pop = population, or the number of pieces of equipment (number/day).

hp = average horsepower for the equipment (unitless).

Load = load factor of the equipment (unitless).

Activity = hours of daily operation of the equipment (hr/day/number).

p = pollutant.

i = equipment type.

Emission factors for selected equipment are displayed in the **Generators/Pumps Emission Factors** screen. The factors were obtained from a combination of sources, as identified in Table G-40. For natural gas emergency generators, conversion from the source emission factor in lb per MMBTU of fuel input (lb/MMBTU) to CalEEMod emission factor in grams per brake horsepower hour is derived according to the following equation.

$$\mathrm{CF} = \mathrm{UC}_1 \times \mathrm{UC}_2 \times \mathrm{BSFC} \div \mathrm{UC}_3$$

Where:

CF = conversion factor (3.1752 g/hp-hr).

UC_1 = unit conversion from MMBTU to lb (1 lb/MMBTU).

UC_2 = unit conversion from BTU to MMBTU (1 MMBTU/1,000,000 BTU).

BSFC = average brake-specific fuel consumption (7,000 BTU/hp-hr).

UC_3 = unit conversion from grams to lb (0.00220462262 lb/g).

For natural gas emergency generators, conversion from the source emission limit of parts per million by volume (ppmv) to CalEEMod emission factor in lb per MMBTU of fuel input (lb/MMBTU) is performed as:

$$\mathrm{EF}_p = \mathrm{EL}_p \times \frac{1}{\mathrm{M}_{vol}} \times \mathrm{MW} \times \mathrm{Fd} \times \mathrm{vv\%} \div (\mathrm{vv\%} - \mathrm{O}_2)$$

Where:

EF = emission factor (lb/MMBTU).

EL = emission limit (ppmv).

M_{vol} = molar volume (379.5 dscf/lbmol @ 14.696 psia, 60 deg. F).

MW = molecular weight (lb/lb-molar volume). The molecular weight for ROG is set at 86 lb/lbmol based on Hexane.

Fd = 8,579 dscf/MMBTU for 1020 BTU/scf Natural Gas @60 deg F.

vv% = reference concentration of oxygen in the air (20.9%)

O_2 = oxygen percentage (South Coast AQMD Rule 1110.2 limits are based on 15 percent oxygen).

p = pollutant.

5.8.2 Process Boilers Screen

The user must enter the number of boilers, fuel type, boiler rating, daily heat input, and annual heat input. Emissions for process boilers are calculated according to the following equation.

$$\mathrm{E}_p = \sum_i (\mathrm{EF}_i \times \mathrm{Pop}_i \times \mathrm{F}_i)$$

Where:

E = total daily boiler emissions (lb/day).

EF = emission factor (lb/MMBTU) (Table G-41).

Pop = population, or the number of boilers (number/day).

F = boiler fuel consumption (MMBTU/number).

p = pollutant.

i = boiler type.

5.8.3 Boilers Emission Factors Screen

Emission factors for selected boilers are displayed in the **Boiler Emission Factors** screen. The factors were obtained from a combination of sources, as identified in Table G-41. Where applicable, a diesel heat value of 140 MMBTU/10^3 gal is used to convert the source emission factor in terms of lb/10^3 gal to the CalEEMod emission factor in terms of lb/MMBTU. A natural gas heat value of 1,020 BTU/scf is used to convert the source emission factor in terms of lb/10^6 scf to the CalEEMod emission factor in terms of lb/MMBTU.

5.9 User Defined Submodule

5.9.1 User Defined Screen

The **User Defined** screen allows the user to input daily and annual emissions in terms of lb per day and tons (short and metric) per year, respectively, generated by any emission source not captured in prior screens. Emissions must be manually entered by the user. Any emissions entered on the screen will be transferred to the appropriate reports.

6 Vegetation Module

The **Vegetation** module calculates GHG emissions (or removals) from land use change and changes in sequestration from tree planting (or removal).

6.1 Land Use Change Screen

The **Land Use Change** screen estimates changes in CO_2 associated with soil and aboveground and belowground biomass resulting from a project-induced change in land use type. The user must define the initial acres of each vegetation land use type prior to construction of the project and the final acres after implementation of the project. CalEEMod will calculate the stored carbon under both conditions. If the existing land use cover currently includes stored carbon, and that value exceeds that of the new land cover type, the land use change would result in GHG emissions. Conversely, if the stored carbon under the final with project conditions exceeds that of initial conditions, the land use change would result in a GHG benefit (i.e., reduction).

Aboveground and belowground carbon storage is calculated according to the following equation.

$$E = (((H_{initial} - H_{final}) \times BCA) \times ((H_{initial} - H_{final}) \times SCA \times SC)) \times R$$

Where:

E = CO_2 benefit (or emissions) from land cover type over the accumulation period (MT CO_2 per year).

$H_{initial}$ = initial acres of land by land-cover type prior to implementation of the project (acres). Available land cover types are based on those defined in CARB's natural and working lands (NWL) GHG inventory.

H_{final} = final acres of land by land-cover type after implementation of the project (acres).

BCA = annual above and belowground biomass carbon accumulation by land cover type (MT carbon per acre per year) (Table G-42). CalEEMod selects the appropriate accumulation rate based on the project location (at the air basin scale) and user-selected land cover type. The rates were developed by CARB (2021f) from their NWL inventory. The rates have been annualized over the following accumulation periods.

- *Forest* = 60 years. This is the median project duration under the California Climate Investments Forest Health Quantification Method for the California Department of Forestry and Fire Protection's Forest Health Program. The median project duration represents one stand rotation, which is the typical time to harvest (CARB 2021g).
- *Grasslands* = 20 years. This represents the typical amount of time for restored grasslands on former agricultural sites to accumulate the same amount of biomass carbon as native grasslands (Matamala et al. 2008).
- *Shrublands* = 35 years. This rate represents the average frequency of wildfires in Southern California Chaparral systems (Luo et al. 2007).

Note that CalEEMod assumes a 0 biomass carbon accumulation rate for the "Urban" land cover type. Users must provide the accumulation rate when the "Other" land cover type is selected.

$H_{initial}$ = initial acres of land by soil type prior to implementation of the project (acres). The soil types and land use types are based on those defined in CARB's Benefits Calculator Tool for Agricultural Lands Conservation (CARB 2020e). The soil type for the project area can be obtained from UC Davis' SoilWeb (UC Davis n.d.). CARB's Agricultural Lands Conservation Easement Quantification Methodology provides detailed instructions for using this tool (CARB 2020f).

H_{final} = final acres of land by soil type after implementation of the project (acres).

SCA = annual soil carbon accumulation by soil type and land use type (MT carbon per acre per year) (Table G-43). The rates are from CARB's (2020e) Benefits Calculator Tool for Agricultural Lands Conservation. The rates have been annualized over a 20-year accumulation period, consistent with IPCC's (2006) GHG inventory framework.

SC = soil carbon gain from conversion from settlements to vegetated land (30%) (CARB 2020a).

R = molecular weight ratio of CO_2 to carbon (44 g CO_2 /12 g carbon).

6.2 Sequestration Screen

The **Sequestration** screen allows the user to input changes in GHGs, criteria pollutants, and energy from tree planting and/or removal. The user is directed to the U.S. Forest Service (USFS) (2021) i-Tree Planting tool. The i-Tree Planting tool quantifies increased carbon sequestration from urban tree planting using species-based biomass equations that account for user defined site-specific variables and tree growth rates. The tool also quantifies GHG reductions from energy savings (e.g., kWh), if applicable.

While simplified quantification methods for increased carbon sequestration resulting from urban tree planting have been used in the past, CalEEMod does not recommend their application given the number and dynamic nature of variables that can influence the amount of CO_2 reduced. Tools like i-Tree Planting comprehensively account for these variables, enabling the user to easily calculate the approximate benefits from individual trees.

The i-Tree Planting tool is available at: https://planting.itreetools.org/. The following user inputs are required for the i-Tree Planting tool.

- *Project state/province*.
- *Project county/division*.
- *Project city*.
- *Project lifetime*. Trees sequester CO_2 while the trees are actively growing. The i-Tree Planting tool will project the benefits for up to 99 years into the future. The tool defaults to 40 years.
- *Tree mortality over project lifetime*. The i-Tree Planting tool will incorporate tree mortality into the projected benefits.
- *Tree species planted by the project*. The user may select from a dropdown menu.
- *Diameter breast height of each tree*. The diameter of the trunk measured at 4.5 feet above the ground at the time of planting.
- *Distance to the nearest building*. For trees that will be planted to shade buildings, enter the distance class to the nearest building (0–19 feet, 20–39 feet, 40–59 feet, > 60 feet). Note that this could be a building on an adjacent site. The i-Tree tool will not calculate shade benefits (i.e., energy savings) for trees more than 60 feet away from the building.
- *Direction of tree from the building*. General direction of the tree from the building (e.g., north 0 degrees). This input can be ignored if the tree is more than 60 feet from the building.
- *Building vintage*. The age of the building affects its energy efficiency and therefore the potential benefits the trees can bring. Available inputs are built after 1980, built 1950–1980, and built before 1950. If the specific age of the building is unknown, the user can input the typical age of buildings for the area where the user is working. This input can be ignored if the tree is more than 60 feet from the building.
- *Building climate controls*. Trees can only have an impact on energy use in buildings where energy is used to heat or cool. Available inputs are heating and air conditioning (A/C), heat only, A/C only, and none. If the climate controls of the building are unknown, the user can input the option that is most common for the area where the user is working. This input can be ignored if the tree is more than 60 feet from the building.
- *Tree condition*. The condition of the trees will affect how well they grow and thus future benefits. Available inputs are excellent, good, fair, poor, critical, dying, and dead. New plantings are likely to be excellent.

- *Tree exposure to sunlight*. The exposure to sunlight affects both how the trees grow and the degree to which a new tree adds shade to a building. Available inputs are full sun, partial shade, and full shade.
- *Carbon intensity of local electricity provider.* See the **Utility Information** screen to obtain the utility emission factors for the project run (Table G-3).
- *Carbon intensity of natural gas*. See Table G-4.

The i-Tree outputs are all expressed over the project lifetime. It is critically important that the user input the same operational lifetime in the “Operational Lifetime (years)” text box as assumed in the i-Tree Planting Calculator model run. This is because CalEEMod divides the user-input lifetime values by the operational lifetime (years) to obtain annual results for the report.

The input field labels in CalEEMod match the i-Tree Planting Calculator outputs. The user should directly copy the outputs from the i-Tree Planting Calculator to the applicable fields in the **Sequestration** screen. If the i-Tree output reports a negative result, be sure to include the negative sign when copying the value to CalEEMod. For example, if i-Tree outputs -1,000 MMBTU for “Fuel Saved,” this means that the project would increase fuel consumption by 1,000 MMBTU. CalEEMod is programmed to read all negative user inputs as increases and positive user inputs as reductions (except as noted in the following paragraph). Note that the “PM2.5 Removed” field represents total PM2.5. CalEEMod internally calculates PM2.5 dust and PM2.5 exhaust from this input assuming each constituent represents 50 percent of total PM2.5. This fraction is based on ambient air monitoring presented in the Bay Area Air Quality Management District’s (2017:2-18) 2017 Clean Air Plan. Because the i-Tree Planting Calculator does not output PM10 removed or avoided, CalEEMod calculates these values as the product of PM2.5 and 367 percent. The value of 367 percent represents the percent of PM10 that is PM2.5, based on the South Coast AQMD’s (2006) *Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds*.

The input field labels are identified in terms of *avoided* emissions or energy consumption. These labels are used in both the “Removed Trees” and “Added Trees” sections to maintain consistency with the i-Tree output. CalEEMod automatically reverses the sign of all user inputs to the “Added Tree” section to account for the fact that these emissions and energy uses would be *reductions* (except when new trees increase fuel consumption by overshading, in which case, addition of the trees would yield a fuel consumption increase). Therefore, users should run i-Tree in the same manner for both removed and added trees.

7 Measures Module

7.1 Emissions Reduction Submodule

The **Introduction** screen provides instructions for navigating through the nine sector screens within the **Emissions Reduction** submodule. The sector names generally match the sector names used in CAPCOA’s *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Designed for Local Governments, Communities, and Project Developers* (Handbook), except for the Area Sources sector, which is a combination of the Handbook’s lawn and landscaping measures, one of its energy measures, and various measures not included in the Handbook that result in non-GHG emission reductions.

Within each sector screen, measures are categorized as either “Quantified” or “Qualitative or Supporting Measures.” Click the notepad icon to the right of the measure title to show the measure factsheet (if available) or measure description. Measures that were preselected on the **Climate**

Map and **Health and Equity Map** screens are shown in *italics*. The five most relevant measures, if any for the screens, for addressing environmental and health burdens of the project site are identified with an asterisk (*).

Most of the emission reduction measures are from quantification methods and underlying data sourced directly from the Handbook, with some modifications being made to facilitate automated quantification based on available information contained within the CalEEMod interface. Handbook measure numbers and titles are directly used in CalEEMod for easy cross reference. CalEEMod also includes a handful of measures that are not presented in the Handbook. These measures exclusively target criteria pollutants, like fugitive dust from construction and VOCs from architectural coatings. The CalEEMod specific measures are numbered sequentially following Handbook measures within the same sector.

CalEEMod includes analytics to estimate emission reductions and some co-benefits achieved by quantified measures. Not all measures reduce the same pollutants or achieve the same co-benefits. Table C-11 identifies the quantified emissions and co-benefits by measure. See Section 4.3.7, *Measures Module*, in the User Guide for definitions of the co-benefit categories. Table C-11 only identifies those co-benefits quantified by CalEEMod. Table G-44 presents all co-benefits that are likely to result from measure implementation (inclusive of quantified measured and qualitative or supporting measures). Use the “Filter Measures” button to view measures that achieve desired co-benefits.

Table C-11. Quantified Emission Reductions and Co-Benefits by Measure

Measure #	Quantified Criteria Pollutants											Quantified Greenhouse Gases							Quantified Co-Benefits [a]				
	TOG	ROG	NO$_x$	CO	SO$_2$	PM10			PM2.5			CO$_2$			CH$_4$	N$_2$O	R	CO$_2$e	VMT	Electricity	Natural Gas	Water	Waste
						Ex	Dust	Tot	Ex	Dust	Tot	Bio	N-Bio	Tot									
C-1-A	X	X	X	X	X	X		X	X		X		X	X	X	X		X		X			
C-1-B	X	X	X	X	X	X		X	X		X		X	X	X	X		X					
C-3	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
C-5	X	X	X	X	X	X		X	X		X		X	X	X	X		X					
C-6						X		X	X		X												
C-7			X																				
C-8		X	X	X		X		X	X		X												
C-9							X	X		X	X												
C-10-A							X	X		X	X												
C-10-B							X	X		X	X												
C-10-C							X	X		X	X												
C-11							X	X		X	X												
C-12							X	X		X	X												
C-13		X																					
T-1	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-2	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-3	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-4	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-5	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-6	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-7	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-8	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-9	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-10	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-12	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-13	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-15	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-16	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-17	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-18	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-19-A	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-19-B	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-20	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-21-A	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-21-B	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X			
T-22-A	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-22-B	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-22-C	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-23	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-24	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-25	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				

Measure #	Quantified Criteria Pollutants											Quantified Greenhouse Gases							Quantified Co-Benefits [a]				
	TOG	ROG	NO_x	CO	SO_2	PM10			PM2.5			CO_2			CH_4	N_2O	R	CO_2e	VMT	Electricity	Natural Gas	Water	Waste
						Ex	Dust	Tot	Ex	Dust	Tot	Bio	N-Bio	Tot									
T-27	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
T-29	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
E-1	X	X	X	X	X	X		X	X		X		X	X	X	X		X		X	X		
E-2	X	X	X	X	X	X		X	X		X		X	X	X	X		X		X	X		
E-4	X	X	X	X	X	X		X	X		X		X	X	X	X		X		X	X		
E-5	X	X	X	X	X	X		X	X		X		X	X	X	X		X		X	X		
E-6													X	X	X	X		X		X			
E-10-A													X	X	X	X		X		X			
E-10-B													X	X	X	X		X		X			
E-10-C													X	X	X	X		X		X			
E-11													X	X	X	X		X		X			
E-12-A	X	X	X	X	X	X		X	X		X		X	X	X	X		X			X		
E-12-B	X	X	X	X	X	X		X	X		X		X	X	X	X		X		X	X		
E-13	X	X	X	X	X	X		X	X		X		X	X	X	X		X		X	X		
E-15													X	X	X	X		X		X			
E-16													X	X	X	X		X		X			
E-17													X	X	X	X		X		X			
LL-1	X	X	X	X	X	X		X	X		X		X	X	X	X		X					
W-1												X	X	X	X	X		X				X	
W-2												X	X	X	X	X		X				X	
W-3												X	X	X	X	X		X					
W-4												X	X	X	X	X		X				X	
W-5												X	X	X	X	X		X				X	
W-6												X	X	X	X	X		X				X	
W-7												X	X	X	X	X		X				X	
S-1/S-2												X	X	X	X	X		X					X
R-1																	X	X					
R-2																	X	X					
R-3																	X	X					
R-4																	X	X					
R-5																	X	X					
R-6																	X	X					
N-1													X	X				X					
N-2		X	X		X	X	X	X	X	X	X		X	X	X	X		X		X	X		
AS-1		X																					
AS-2		X																					
E-14	X	X	X	X	X	X		X	X		X	X	X	X	X	X		X			X		
M-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
M-2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
M-3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					

CH_4 = methane; CO = carbon monoxide; CO_2e = carbon dioxide equivalent; Ex = exhaust; tot = total; Bio = biological; N-bio = non-biological; N_2O = nitrous oxide; NO_x = nitrogen oxides; R = refrigerant; ROG = reactive organic gases; SO_2 = sulfur dioxide; TOG = total organic gases; VMT = vehicle miles travelled.

[a] "X" does not necessarily mean the co-benefit is always quantified. For some emissions and co-benefits, quantification depends on user inputs.

As discussed further in Section 4.3.7.1, *Emissions Reduction Submodule*, in the User Guide, emissions reductions achieved by several measures may be quantified by equally applying the reduction efficacy to all land use subtypes in the project run, or through targeted application to specific land use subtypes. The user may be prevented from selecting certain measures because they are not applicable to the project land use types and/or project scale, are exclusive to other measure selections, or depend on other measures selections that have not been made. See Tables G-45 and G-46 for the applicable land use subtypes and project scales by measure, respectively. Further detail on measure dependencies and mutual exclusivity is provided below in the below sections, where relevant.

The following sections provide additional information on assumptions, calculations, or parameters that are unique to quantified measures in individual screens within the **Emissions Reduction** submodule.

7.1.1 Construction

CalEEMod includes 14 quantified construction measures. Measures C-1-A through C-8 (non-inclusive) reduce combustion emissions. Measures C-9 through C-12 reduce fugitive dust. Measure C-13, *Low VOC-Paints for Construction*, reduces VOC emissions from architectural coatings.

CalEEMod prohibits the user from selecting measures that would not be feasible based on prior user inputs. Specifically:

- Measure C-5, *Use Advanced Engine Tiers*, and Measure C-6, *Use Diesel Particulate Filters*, only apply to diesel-fueled equipment. They cannot be selected if the equipment inventory defined in the **Off-Road Equipment** screen does not include diesel equipment.
- Measure C-6, *Use Diesel Particulate Filters*, and Measure C-8, *Use Renewable Diesel,* cannot be implemented for Tier 4 Final equipment, either identified in **Off-Road Equipment** screen or through application of Measure C-5, *Use Advanced Engine Tiers*.
- Measures C-6, *Use Diesel Particulate Filters*, and C-8, *Use Renewable Diesel,* are mutually exclusive.
- Measure C-9, *Use Dust Suppressants*, and Measure C-10-A, *Water Exposed Surfaces*, are mutually exclusive.
- Measures C-9 through C-12 cannot be selected if the user has already selected them as a control strategy in the **Dust from Material Movement**, **Demolition**, and/or **On-Road Fugitive Dust** screens.

Default low-VOC limits for Measure C-13, *Low VOC-Paints for Construction,* are provided based on the MPI Green Performance Standard. The user may override these defaults with a project-specific performance standard, if available. The low-VOC content limit must not exceed the VOC content in the **Architectural Coatings** screen that is used to quantify unmitigated emissions.

7.1.2 Transportation

CalEEMod includes 27 quantified transportation measures. Most of the measures aim to reduce VMT and encourage mode shifts from single-occupancy vehicles to shared (e.g., transit) or active modes of transportation (e.g., bicycle). Quantification of some measures that are quantified in the Handbook is not currently supported by CalEEMod due to differences in underlying analysis methods and/or limitations around appropriately accounting for the net change in emissions resulting from measure implementation. Handbook transportation measures that are not quantified by CalEEMod are presented as “Qualitative or Supporting Measures.”

As discussed above, for all emission reduction measures, CalEEMod has identified the land use subtypes and project scale to which they are applicable (see Tables G-45 and G-46). The user is precluded from selecting measures that are not applicable to the project land use subtype(s) and project scale. The applicability analysis for transportation measures also accounts for the project locational context, as defined in the **Administrative Map** and **Project Detail** screens. The locational context refers to the level of development at the census tract level. The three locational contexts identified in CalEEMod are suburban, urban, and rural, as defined in Table C-12. Most transportation measures are applicable to development within at least one of these three locational context areas (refer to Table G-47).

Table C-12. CalEEMod Locational Context Options [a, b]

Place Type Name	Place Type Description	CalEEMod Locational Context
Urban Low Transit	Good accessibility, low vacancy, middle-aged housing stock (San Jose, Orange County, San Diego, Los Angeles outside of downtown area)	Urban
Central City Urban	Very high density, excellent accessibility, high public transit access, low single-family homes, older high-value housing stock (mostly downtown San Francisco)	Urban
Urban High Transit	High density, good accessibility, high public transit access, low single-family homes, middle-aged and older housing stock (downtown Los Angeles, Berkeley, Oakland, San Francisco outside downtown area)	Urban
Suburb With Multi-Family Housing	Average on most indicators for the state, low single-family homes and low housing values	Suburban
Suburb With Single-Family Homes	Low density and accessibility, low vacancy, high newer single-family homes and high housing values	Suburban
Rural	Very low access, high vacancy, high newer single-family homes with lower housing values (mainly outside population centers of any kind)	Rural
Rural-In-Urban	These tracts have slightly better accessibility than the truly "rural" tracts, and are more likely to have multifamily housing (select tracts within urbanized areas that had been classified as "Rural")	Rural

[a] The CalEEMod locational context inputs were developed from the eight place types described in *Quantifying the Effect of Local Government Actions on VMT* (Salon 2014).
[b] A “NA” value will be returned for the locational context if the project census tract is identified as “preserve land” or if the project census tract is not mapped in the locational context geospatial domain.

CalEEMod accounts for potential interactions among transportation measures. As discussed further in the Handbook, each transportation measure has a maximum allowable VMT reduction. Measures are grouped into six subsectors (e.g., Land Use, Neighborhood Design), which also have a maximum allowable sub-sector VMT reduction. Finally, the Handbook adopts 70 percent as a maximum for the combined VMT impact from the Land Use, Neighborhood Design, Parking or Road Pricing/Management, and Transit subsectors. CalEEMod applies the measure and sub-sector maxima from the Handbook to the suite of user-selected measures to ensure that emissions are not double counted.

Many of the transportation measures are mutually exclusive. CalEEMod is programmed with mutual exclusivity rules as outlined in the Handbook (see the Mutually Exclusive Measures section of the quantification methods for each transportation measure, as applicable). CalEEMod prohibits the user from selecting mutually exclusive transportation measures.

7.1.3 Energy

CalEEMod includes 14 quantified energy measures. The measures aim to improve building energy efficiency, increase renewable energy generation, and electrify building end uses. Like transportation sector measures, not all energy measures that are quantified in the Handbook are currently supported as quantified measures in CalEEMod. Handbook energy measures that are not quantified by CalEEMod are presented as “Qualitative or Supporting Measures.”

CalEEMod is programmed with a series of rules to account for potential interactions among energy measures. These rules are applied after the user has selected all energy measures to recalculate building energy consumption and quantify mitigated emissions. Specifically, if selected:

- Energy reductions (or increases) from Measure E-4, *Install Cool Roofs and/or Cool Walls in Residential Development*, and Measure E-5, *Install Green Roofs in Place of Dark Roofs*, are quantified as absolute values and are assessed first.
- Energy reductions from Measure E-1, *Buildings Exceed 2019 Title 24 Building Envelope Energy Efficiency Standards*, are quantified as a percent reduction and are assessed next.
- Building electrification measures (E-12-A, E-12-B, E-13, and E-15) change the energy consumption profile and are assessed after energy efficiency measures (E-1, E-2, E-4, and E-5).
- Electricity reductions from renewable energy measures (E-10-A, E-10-B, E-10-C) are assessed next.
- Energy reductions from net zero and renewable surplus buildings (E-16 and E-17) are assessed last.

The recalculated building electricity consumption (kWh) is translated to mitigated emissions using the same utility emission factors as specified in **Utility Information** screen, unless the user selects Measure E-11, *Procure Electricity from Lower Carbon Intensity Power Supply*. If this measure is selected, mitigated electricity emissions are calculated using the utility emission factors input by the user for the measure.

CalEEMod is also programmed with mutual exclusivity rules as outlined in the Handbook (see the *Mutually Exclusive Measures* section of the quantification methods for each energy measure, as applicable). CalEEMod prohibits the user from selecting mutually exclusive energy measures.

7.1.4 Water

CalEEMod includes seven quantified water measures. The measures aim to reduce water consumption and/or require a less energy-intensive water source. Like energy sector measures, CalEEMod is programmed with a series of rules to account for potential interactions among water measures. These rules are applied after the user has selected all water measures to recalculate indirect energy consumption and quantify mitigated emissions. Specifically, if selected:

- Measure W-3, *Use Locally Sourced Water Supply*, reduces the energy intensity required to treat and distribute water. The user supplied electricity intensity value is applied to subsequent water measures, as applicable.
- Indirect electricity reductions from measures W-1, *Use Reclaimed Non-Potable Water*; W-2, *Use Grey Water*; W-4, *Require Low-Flow Water Fixtures*; W-5, *Design Water-Efficient Landscapes*; and W-6, *Reduce Turf in Landscapes and Lawns*, are quantified as absolute values and are assessed next.
- Indirect electricity reductions from Measure W-7, *Adopt a Water Conservation Strategy*, are quantified as a percent reduction and are assessed next.

The recalculated indirect electricity consumption (kWh) is translated to mitigated emissions using the same utility emission factors as specified in **Utility Information** screen.

7.1.5 Waste

CalEEMod includes one quantified waste measure. Measure S-1/S-2, *Implement Waste Reduction Plan*, allows the user to identity the percent reduction in project waste that will be sent to regional landfills, avoiding CH_4 emissions from landfill waste decomposition and combustion, if applicable.

7.1.6 Refrigerants

CalEEMod includes six quantified refrigerant measures. Most of these measures aim to decrease the charge size and/or leak rate of equipment or replace the baseline refrigerant with a lower GWP refrigerant. Measure R-2, *Install Secondary Loop and/or Cascade Supermarket Systems in Place of Direct Expansion Systems*, and Measure R-3, *Install Transcritical* CO_2 *Supermarket Systems in Place of High-GWP Systems*, are mutually exclusive.

7.1.7 Natural Lands

CalEEMod includes two quantified natural lands measures. These measures are linked to the **Vegetation** module. User inputs to the **Land Use Change** screen will auto-load under Measure N-1, *Create New Vegetated Open Space*, and user inputs to the **Sequestration** screen will auto-load under Measure N-2, *Expand Urban Tree Planting*. These inputs inform the calculation of unmitigated emissions. If through the implementation of mitigation, the project changes or expands any of these inputs, the user should provide the necessary information in this screen. For example, consider a scenario in which the user identifies in the **Land Use Change** screen that there are 10 acres of initial grazing area, and the project reduces that to 5 acres. These inputs will automatically show as the "Initial Acres" and “Final Acres” under Measure N-1. With Measure N-1, the project will avoid impacting the 5 acres previously identified in the **Land Use Change** screen. In this example, the user should change the auto-loaded “Final Acres” (5 acres) under N-1 in the **Natural Lands** screen to 10 acres.

7.1.8 Area Sources

CalEEMod includes four quantified area source measures. Measures AS-1, *Use Low-VOC Cleaning Supplies*, and AS-2, *Use Low-VOC Paints*, reduce VOC emissions from cleaning supplies and architectural coatings (i.e., paints), respectively. The emission factor for low-VOC cleaning supplies is further defined in Appendix D3, *Consumer Products Use*. Default low-VOC limits for paints are provided based on the MPI Green Performance Standard. The user may override these defaults with a project-specific performance standard, if available. The low-VOC content limit must not exceed the VOC content in the **Architectural Coatings** screen that is used to quantify unmitigated emissions.

Measure E-14, *Limit Wood Burning Devices and Natural Gas/Propane Fireplaces in Residential Development*, allows the user to require only natural gas hearths, no hearths, or no wood-burning fireplaces.

Measure LL-1, *Replace Gas Powered Landscape Equipment with Zero-Emission Landscape Equipment*, allows the user to require electric landscaping equipment. This measure is only available if the user manually inputs gasoline-powered landscaping equipment in the **Landscaping Equipment** screen.

7.1.9 Miscellaneous

CalEEMod includes three quantified miscellaneous measures. There are no available defaults. The efficacy of each measure is influenced by specific implementation consideration that are unique to each individual project. These parameters and conditions cannot be known or anticipated by CalEEMod. Accordingly, all three measures require the user to input the amount of pollutant reduced per year.

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