California Air Resources Board

Quantification Methodology

Strategic Growth Council
Affordable Housing and Sustainable Communities Program

California Climate Investments

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Table of Contents

List of Acronyms and Abbreviations

Acronym	Term
AHSC	Affordable Housing and Sustainable Communities
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CMAQ	Congestion Mitigation and Air Quality
Diesel PM_{10}	diesel particulate matter with a diameter less than 10 micrometers
DC	direct current
g	grams
gal	gallons
gCO_2e/MJ	grams of carbon dioxide equivalent per megajoule
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
ICP	Integrated Connectivity Project Area
kg	kilograms
kWh	kilowatt hours
lbs	pounds
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	nitrous oxide
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
PV	photovoltaic
RIPA	Rural Innovation Project Area
ROG	reactive organic gas
scf	standard cubic feet
SGC	Strategic Growth Council
TOD	Transit Oriented Development Project Area
VMT	vehicle miles traveled

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating GHG emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

CARB is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the GGRF. This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefit calculator tools. CARB develops these methodologies and tools based on the project components eligible for funding by each administering agency, as reflected in the program expenditure records available at: www.arb.ca.gov/cci-expenditurerecords.

For the SGC AHSC Program, CARB developed this AHSC Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project type. This methodology uses calculations to estimate GHG emission reductions from avoided passenger VMT as a result of land use, housing, and transportation strategies to support infill, compact, and affordable housing development projects, in addition to GHG emission reductions from solar PV electricity generation.

The AHSC Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with a project example, and outlines documentation requirements. Applicants will estimate and SGC will report the total project GHG emission reductions and co-benefits estimated using the AHSC Benefits Calculator Tool, as well as the total project GHG emission reductions per dollar of GGRF funds requested. The AHSC Benefits Calculator Tool is available for download at: www.arb.ca.gov/cci-resources.

Using many of the same inputs required to estimate GHG emission reductions, the AHSC Benefits Calculator Tool estimates the following co-benefits and key variables from AHSC projects:

- Passenger VMT reductions (miles);
- Net density (dwelling units per acre);
- Renewable energy generation (kWh);
- Local and remote ROG emission reductions (lbs);
- Local and remote NO_x emission reductions (lbs);
- Local and remote $PM_{2.5}$ emission reductions (lbs);
- Local diesel PM_{10} emission reductions (lbs);

- Fossil fuel use reductions (gallons);
- Travel cost savings ($); and
- Energy and fuel cost savings ($).

Additional co-benefits for which CARB assessment methodologies were not incorporated into the Benefits Calculator Tool may also be applicable to the project. Applicants should consult the AHSC Guidelines[1], solicitation materials, and agreements to ensure they meet AHSC requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[2] CARB developed this AHSC Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project level;
- Provide uniform methods to be applied statewide and be accessible by all applicants;
- Use existing and proven tools and methods, where available and appropriate;
- Use project-level data, where available and appropriate; and
- Result in GHG emission reduction estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the AHSC project types. CARB also consulted with SGC to determine the project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level.

CARB released the Draft AHSC Quantification Methodology and Draft AHSC Benefits Calculator Tool for public comment in September 2020. This Final AHSC Quantification Methodology and accompanying AHSC Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the AHSC Guidelines.

The "Methods to Find the Cost-effectiveness of Funding Air Quality Projects for Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement Projects" were the basis for developing the GHG emission

[1] Strategic Growth Council. sgc.ca.gov/programs/ahsc/resources/guidelines.html
[2] California Air Resources Board. www.arb.ca.gov/cci-fundingguidelines

reduction estimates for transit and connectivity project features.[3] The CMAQ Methods are equations for evaluating the cost-effectiveness of certain types of transportation projects, such as bicycle paths, vanpools, and new bus services. CARB and the California Department of Transportation developed the CMAQ Methods, which are used statewide by transportation agencies to assess criteria and toxic pollutant emission reductions from transportation projects competing for State motor vehicle fee and federal CMAQ funding. All of the CMAQ Methods equations and assumptions needed for this quantification method are included in this document, and some assumptions have been modified as necessary. Therefore, the equations presented in this Quantification Methodology are referred to as Transit and Connectivity Methods. The CMAQ Methods Guide is available at: www.arb.ca.gov/planning/tsaq/eval/eval.htm.

To develop VMT reduction estimates for projects that include affordable housing developments, the AHSC Benefits Calculator Tool uses information from the California Statewide Travel Demand Model,[4] metropolitan planning organizations,[5] the Institute of Transportation Engineers Trip Generation Manual[6] and Parking Generation Manual,[7] and the California Air Pollution Control Officers Association "Quantifying Greenhouse Gas Mitigation Measures" report[8] and California Emissions Estimator Model®.[9] The AHSC Benefits Calculator Tool adapts a methodology from this model for ease of use and alignment with the specific requirements of the AHSC Program.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. Co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

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[3] California Air Resources Board and California Department of Transportation. *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects for Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement Projects.* May 2005. ww2.arb.ca.gov/resources/documents/congestion-mitigation-and-air-quality-improvement-cmaq-program

[4] California Department of Transportation. *California Statewide Travel Demand Model.* 2016. dot.ca.gov/programs/transportation-planning/multi-modal-system-planning/statewide-modeling

[5] The Association of Monterey Bay Area Governments, Butte County Association of Governments, Metropolitan Transportation Commission, Sacramento Area Council of Governments, San Luis Obispo Council of Governments, and Southern California Association of Governments provided trip length data for this AHSC Quantification Methodology.

[6] Institute of Transportation Engineers. *Trip Generation Manual, 10th Edition.* 2017. www.ite.org/technical-resources/topics/trip-and-parking-generation/trip-generation-10th-edition-formats/

[7] Institute of Transportation Engineers. *Parking Generation Manual, 4th Edition.* 2010. www.ite.org/technical-resources/topics/trip-and-parking-generation/

[8] California Air Pollution Control Officers Association. *Quantifying Greenhouse Gas Mitigation Measures.* 2010. www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf

[9] California Air Pollution Control Officers Association. *California Emissions Estimator Model, version 2016.3.2.* 2017. www.caleemod.com.

The AHSC Quantification Methodology and AHSC Benefits Calculator Tool are applicable only to AHSC project types and should not be used to estimate GHG emission reductions or co-benefits for any projects which do not meet AHSC Program requirements.

Tools

The AHSC Benefits Calculator Tool relies on project-specific outputs from the National Renewable Energy Laboratory PVWatts® Calculator, a web-based tool that estimates the electricity production of grid-connected roof- or ground-mounted solar PV systems. PVWatts calculates estimated values for the proposed system's monthly and annual electricity production. For projects that include solar PV systems, the AHSC Benefits Calculator Tool relies on estimates of solar PV electricity generation from PVWatts. PVWatts is publicly available to anyone with internet access, free of charge, and subject to regular updates to incorporate new information. The tool can be accessed at: pvwatts.nrel.gov.

In addition to PVWatts, the AHSC Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database, available at: www.arb.ca.gov/cci-resources. The Emission Factor Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the AHSC Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The AHSC Benefits Calculator Tool and User Guide can be downloaded from: www.arb.ca.gov/cci-resources.

Updates

CARB staff periodically review each quantification methodology to evaluate its effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the AHSC Quantification Methodology and AHSC Benefits Calculator Tool from the previous versions[10] to enhance the analysis and provide additional clarity, including the following additions:

- Guidance to clarify frequently asked questions;
- Updated GHG emission factors and fuel economy values for passenger autos;
- Simplified inputs for residential parking;

[10] California Air Resources Board. November 2019. www.arb.ca.gov/cci-resources

- Equations to estimate GHG emission reductions and co-benefits from conversion of Class II bike lanes to Class IV separated bikeways and new bicycle boulevards;
- Project-specific useful life and trips inputs for bike share;
- Equations to estimate GHG emissions from bike share collection and distribution vehicles;
- Growth factor adjustments for bicycle infrastructure;
- Annual rather than daily ridership inputs for transit;
- Optional carbon intensity and fuel consumption inputs for transit vehicles;
- Revised guidance on transit vehicle useful life;
- Equations to estimate GHG emission reductions and co-benefits from transit fare reductions;
- Updated data on job center locations; and
  Separate summaries of GHG emission reductions from housing, active transportation, and solar PV components and transit components.

Section B. Methods

The following section provides details on the methods supporting emission reductions in the AHSC Benefits Calculator Tool.

Project Components

SGC developed five categories of eligible costs that meet the objectives of the AHSC Program.[11] For quantification purposes, CARB defined project components within those eligible costs for which there are methods to quantify GHG emission reductions.

Other project features may be eligible for funding under the AHSC Program; however, each project requesting GGRF funding must include at least one of the project components listed in Table 1 below.

Table 1. Project Components by Eligible Cost

Eligible Cost	Project Component
Affordable Housing Development; Housing-related Infrastructure	Construction or substantial rehabilitation of affordable housing, including mixed-use development, and related infrastructure
	Grid-connected solar PV system
Sustainable Transportation Infrastructure; Transportation-related Amenities	New bicycle facility (bicycle boulevard, Class I bike path, Class II bike lane, Class IV separated bikeway, or Class II to IV conversion)
	New walkway
	New bike share equipment[12]
	New or expanded transit service (bus, cable car, ferry, heavy rail, light rail, microtransit shuttle or van, streetcar, trolley bus, or vanpool)
	Capital improvement that encourages mode shift[13]
Program	Transit subsidies
	New bike share operations[12]

[11] Strategic Growth Council. sgc.ca.gov/programs/ahsc/resources/guidelines.html

[12] Bike share infrastructure and fleets are eligible Sustainable Transportation Infrastructure costs according to the AHSC Guidelines, while bike share operations are eligible Active Transportation Program costs. Quantification of the benefits of new bike share infrastructure, fleets, or operations is equivalent regardless of the funding type requested.

[13] Capital improvements are infrastructure or equipment improvements, other than vehicle purchases, that increase transit ridership without increasing transit vehicle emissions.

General Approach

This section describes the methods used in the AHSC Benefits Calculator Tool to estimate GHG emission reductions and air pollutant emission co-benefits by project component. These methods account for emission reductions from avoided passenger VMT and the generation of solar PV electricity.

In general, the GHG and air pollutant emission reductions are estimated in the AHSC Benefits Calculator Tool using the quantification approaches by project component outlined in Table 2 below.

Table 2. General Approach to Quantification by Project Component

Project Component	Emission Reductions Estimated
Affordable housing development or residential transit subsidy	Emissions from avoided passenger VMT
Solar PV electricity generation	Emissions from avoided grid electricity production
New bicycle facility, walkway, or bike share	Emissions from displaced autos (less emissions from electric bikes and collection and distribution vehicles, if applicable)
New or expanded transit service	Emissions from displaced autos less emissions from new service vehicle
Capital improvements or transit fare reductions	Emissions from displaced autos

A. Affordable Housing Developments and Residential Transit Subsidies

The emission reductions from affordable housing developments and residential transit subsidies are calculated as the emission reductions from avoided passenger VMT compared to a baseline scenario lacking VMT reduction measures. Equations 1 through 4 are used to estimate unmitigated VMT for the baseline scenario.[14]

Equation 1: Average Daily Trips per Dwelling Unit

$$Average\ Daily\ Trips = \frac{(Weekday\ Trips * 5) + Saturday\ Trips + Sunday\ Trips}{7\ days}$$

Where,			Units
Average Daily Trips	=	Average daily trip rate per dwelling unit for applicable dwelling type	trips/ dwelling unit-day
Weekday Trips	=	Average weekday trip rate per dwelling unit for applicable dwelling type	trips/ dwelling unit
Saturday Trips	=	Average Saturday trip rate per dwelling unit for applicable dwelling type	trips/ dwelling unit
Sunday Trips	=	Average Sunday trip rate per dwelling unit for applicable dwelling type	trips/ dwelling unit

[14] Equations 1 through 4 use a methodology and trip type and link percentages described in Appendices A and D of the *User's Guide for CalEEMod Version 2016.3.2*. www.aqmd.gov/caleemod/user's-guide
Trip rates are derived from the *Trip Generation Manual, 10th Edition*. www.ite.org/technical-resources/topics/trip-and-parking-generation/trip-generation-10th-edition-formats/
Trip lengths not provided by metropolitan planning organizations are calculated for multi-county regions from the California Statewide Travel Demand Model. dot.ca.gov/programs/transportation-planning/multi-modal-system-planning/statewide-modeling

Equation 2: Primary Trip Length

$$Primary\ Trip\ Length = (H\text{-}W\ Length * H\text{-}W\ Share) + (H\text{-}S\ Length * H\text{-}S\ Share) + (H\text{-}O\ Length * H\text{-}O\ Share)$$

Where,			Units
Primary Trip Length	=	County-specific average length of urban or rural primary home-based trip	miles
H-W Length	=	County-specific average length of urban or rural trip between home and work	miles
H-W Share	=	Statewide default percentage of primary home-based trips which are between home and work (42.3%)	%
H-S Length	=	County-specific average length of urban or rural trip between home and shopping	miles
H-S Share	=	Statewide default percentage of primary home-based trips which are between home and shopping (19.6%)	%
H-O Length	=	County-specific average length of urban or rural trip between home and locations other than work or shopping	miles
H-O Share	=	Statewide default percentage of primary home-based trips which are between home and other locations (38.1%)	%

Equation 3: Overall Trip Length

$$Overall\ Trip\ Length = (Primary\ Trip\ Length * Primary\ Share) + (Primary\ Trip\ Length * 25\% * Diverted\ Share) + (0.1\ miles * Pass\text{-}by\ Share)$$

Where,			Units
Overall Trip Length	=	County-specific average length of urban or rural overall home-based trip	miles
Primary Trip Length	=	County-specific average length of urban or rural primary home-based trip, from Equation 2	miles
Primary Share	=	Statewide average percentage of home-based trips which are primary (86%)	%
Diverted Share	=	Statewide average percentage of home-based trips which are diverted (11%)	%
Pass-by Share	=	Statewide average percentage of home-based trips which are pass-by (3%)	%

Equation 4: Annual Unmitigated VMT

$$Annual\ Unmitigated\ VMT = Average\ Daily\ Trips * Overall\ Trip\ Length * Total\ Units * 365\ days$$

Where,			Units
Annual Unmitigated VMT	=	Annual VMT by residents of housing development without VMT mitigation measures	miles/year
Average Daily Trips	=	Average daily trip rate per dwelling unit for applicable dwelling type, from Equation 1	trips/ dwelling unit*day
Overall Trip Length	=	County-specific average length of urban or rural overall home-based trip, from Equation 3	miles
Total Units	=	Number of dwelling units in affordable housing development	dwelling units

Equations 5 through 16 are used to calculate the expected percent reductions in passenger VMT resulting from the characteristics of the affordable housing development.[15]

Equation 5: VMT Reductions from Increased Density

$$Density\ VMT\ Reductions = \left(\frac{Density - Required\ Density}{Required\ Density}\right) * 7\%$$

Where,			Units
Density VMT Reductions	=	VMT reductions associated with increased net density over required baseline, capped at 30%	%
Density	=	Net density of affordable housing development	dwelling units/acre
Required Density	=	Required baseline net density per Project Area Type, defined by the AHSC Guidelines (see Table 3)	dwelling units/acre

[15] Equations 5 through 17 use methodologies and elasticities described in the *Quantifying Greenhouse Gas Mitigation Measures* report. www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf

Table 3. Minimum Net Density by Project Area Type

Project Area Type	Minimum Net Density (dwelling units per acre)[16]
TOD	30
ICP	20
RIPA	15

Equations 6 and 7 are applicable to mixed-use developments only.

Equation 6: Land Use Index

$$Land\ Use\ Index = -\left[\frac{4 * (0.01 * \ln 0.01) + \left(\left(\frac{RS}{RS+MS}\right) * \ln\left(\frac{RS}{RS+MS}\right)\right) + \left(\left(\frac{MS}{RS+MS}\right) * \ln\left(\frac{MS}{RS+MS}\right)\right)}{\ln 6}\right]$$

Where,			Units
Land Use Index	=	Measure of diversity of land use in mixed-use development	unitless
RS	=	Space for residential uses in mixed-use development	square feet
MS	=	Publically accessible space for commercial or social services uses in mixed-use development	square feet

Equation 7: VMT Reductions from Increased Land Use Diversity

$$Diversity\ VMT\ Reductions = \left(\frac{Land\ Use\ Index - 0.15}{0.15}\right) * 9\%$$

Where,			Units
Diversity VMT Reductions	=	VMT reductions associated with increased land use diversity over baseline, capped at 30%, with increase in land use diversity capped at 500%	%
Land Use Index	=	Measure of diversity of land use in mixed-use development, from Equation 6	unitless

[16] Strategic Growth Council. sgc.ca.gov/programs/ahsc/resources/guidelines.html

The distance to the nearest central business district is identified using US Census data[17] and the CARB mapping tool available at: www.arb.ca.gov/cc/capandtrade/auctionproceeds/kml/jobcentermap.htm.

Equation 8: VMT Reductions from Increased Destination Accessibility

$$Accessibility\ VMT\ Reductions = \left(\frac{12\ miles - Distance}{12\ miles}\right) * 20\%$$

Where,			Units
Accessibility VMT Reductions	=	VMT reductions associated with increased destination accessibility, capped at 20%	%
Distance	=	Distance from affordable housing development to nearest central business district	miles

Equation 9: VMT Reductions from Integration of Affordable Housing

$$Affordability\ VMT\ Reductions = \left(\frac{Affordable\ Units}{Total\ Units}\right) * 4\%$$

Where,			Units
Affordability VMT Reductions	=	VMT reductions associated with integration of affordable dwelling units into housing development, capped at 4%	%
Affordable Units	=	Number of affordable dwelling units in affordable housing development	dwelling units
Total Units	=	Number of dwelling units in affordable housing development	dwelling units

[17] United States Census Bureau. 2018. *Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics – California Workplace Area Characteristics.* lehd.ces.census.gov/data/

Equation 10: Total VMT Reductions from Land Use Measures

$$\textit{Land Use VMT Reductions} = 1 - (1 - \textit{Density VMT Reductions}) * (1 - \textit{Diversity VMT Reductions}) * (1 - \textit{Accessibility VMT Reductions}) * (1 - \textit{Affordability VMT Reductions})$$

Where,			Units
Land Use VMT Reductions	=	VMT reductions associated with all land use measures, capped according to Project Area Type (see Table 4)	%
Density VMT Reductions	=	VMT reductions associated with increased density over required baseline, capped at 35%, from Equation 5	%
Diversity VMT Reductions	=	VMT reductions associated with increased land use diversity over baseline, capped at 30%, from Equation 7	%
Accessibility VMT Reductions	=	VMT reductions associated with increased destination accessibility, capped at 20%, from Equation 8	%
Affordability VMT Reductions	=	VMT reductions associated with integration of affordable dwelling units into housing development, capped at 4%, from Equation 9	%

Table 4. Maximum VMT Reductions by Project Area Type[18]

Project Area Type	Land Use Measures	Land Use, Parking, and Traffic Calming Measures	Total
TOD	65%	70%	75%
ICP	30%	35%	40%
RIPA	5%	10%	15%

[18] VMT reduction caps are aligned with the "urban" location type from the *Quantifying Greenhouse Gas Mitigation Measures* report for TOD, "compact infill" for ICP, and "suburban" for RIPA. www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf

Equation 11: VMT Reductions from Limited Parking Supply

$$Parking\ Supply\ VMT\ Reductions = \left(\frac{Total\ Units * Parking\ Rate - Parking\ Spaces}{Total\ Units * Parking\ Rate}\right) * 50\%$$

Where,			Units
Parking Supply VMT Reductions	=	VMT reductions associated with limited residential parking supply, capped at 12.5%	%
Total Units	=	Number of dwelling units in affordable housing development	dwelling units
Parking Rate	=	Average peak parking demand per dwelling unit for applicable dwelling type	vehicles/ unit
Parking Spaces	=	Number of residential parking spaces in affordable housing development	parking spaces

Equation 12: VMT Reductions from Unbundled Parking Cost

$$Unbundled\ Parking\ VMT\ Reductions = Unbundled\ Cost * \left(\frac{12\ months}{\$4{,}000}\right) * 0.4 * 85\%$$

Where,			Units
Unbundled Parking VMT Reductions	=	VMT reductions associated with unbundled residential parking cost, capped at 20%	%
Unbundled Cost	=	Monthly unbundled cost for on-site residential parking	$/month

Equation 13: Total VMT Reductions from Parking Measures

$$Parking\ VMT\ Reductions = 1 - (1 - Parking\ Supply\ VMT\ Reductions) * (1 - Unbundled\ Parking\ VMT\ Reductions)$$

Where,			Units
Parking VMT Reductions	=	VMT reductions associated with all parking measures, capped at 20%	%
Parking Supply VMT Reductions	=	VMT reductions associated with limited residential parking supply, capped at 12.5%, from Equation 11	%
Unbundled Parking VMT Reductions	=	VMT reductions associated with unbundled residential parking cost, capped at 20%, from Equation 12	%

Equation 14: VMT Reductions from Traffic Calming Measures

$$Traffic\ Calming\ VMT\ Reductions = 1\%$$

Where,		Units
Traffic Calming VMT Reductions	= VMT reductions associated with traffic calming measures within ½ mile of affordable housing development	%

Equation 15: VMT Reductions from Residential Transit Subsidy

$$Subsidy\ VMT\ Reductions = Elasticity * \frac{Recipients}{Total\ Units} * \frac{Duration}{30\ years}$$

Where,		Units
Subsidy VMT Reductions	= VMT reductions associated with transit passes for residents, capped at 20%	%
Elasticity	= Elasticity of VMT specific to annual value of transit passes to residents and urban or rural project setting	unitless
Recipients	= Number of dwelling units receiving transit passes in affordable housing development	dwelling units
Total Units	= Number of dwelling units in affordable housing development	dwelling units
Duration	= Number of years for which transit passes are funded	years

Equation 16: Total VMT Reductions

$$Total\ VMT\ Reductions = Land\ Use\ VMT\ Reductions + Parking\ VMT\ Reductions + Traffic\ Calming\ VMT\ Reductions + Subsidy\ VMT\ Reductions$$

Where,		Units
Total VMT Reductions	= VMT reductions associated with all mitigation measures, capped according to Project Area Type (see Table 3)	%
Land Use VMT Reductions	= VMT reductions associated with all land use measures, capped according to Project Area Type, from Equation 10	%
Parking VMT Reductions	= VMT reductions associated with all parking measures, capped at 20%, from Equation 13	%
Traffic Calming VMT Reductions	= VMT reductions associated with traffic calming measures within ½ mile of affordable housing development, from Equation 14	%
Subsidy VMT Reductions	= VMT reductions associated with transit passes for residents, capped at 20%, from Equation 15	%

Equations 17 and 18 are used to apply the expected percent reductions in VMT to estimate avoided VMT from the affordable housing development.

Equation 17: Annual Avoided VMT

$$Annual\ Avoided\ VMT = Annual\ Unmitigated\ VMT * Total\ VMT\ Reductions$$

Where,			Units
Annual Avoided VMT	=	Annual reductions in baseline residential VMT	miles/year
Annual Unmitigated VMT	=	Annual VMT by residents of housing development without VMT mitigation measures, from Equation 4	miles/year
Total VMT Reductions	=	VMT reductions associated with all mitigation measures, from Equation 16	%

Equation 18: Total Avoided VMT

$$Total\ Avoided\ VMT = Annual\ Avoided\ VMT * 30\ years$$

Where,			Units
Total Avoided VMT	=	Reductions in baseline residential VMT for quantification period of affordable housing development (30 years)	miles
Annual Avoided VMT	=	Annual reductions in baseline residential VMT	miles/year

Equation 19 is used to estimate emission reductions from the avoided VMT associated with the affordable housing development and transit subsidies for residents.

Equation 19: Auto Emission Reductions from Affordable Housing Development and Residential Transit Subsidies

$$Emission\ Reductions = \left(\frac{Annual\ Avoided\ VMT * EF_{Yr1} + Annual\ Avoided\ VMT * EF_{YrF}}{2}\right) * 30\ years * U^{-1}$$

Where,			Units
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of affordable housing development (30 years)	$MTCO_2e$ or lbs
Annual Avoided VMT	=	Annual reductions in baseline residential VMT, from Equation 17	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of project life	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of project life	g/mile
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

B. Solar PV Electricity Generation

The emission reductions from grid-connected solar PV projects are calculated as the emission reductions from avoided fossil-fuel-based electricity generation.[19]

Equation 20: Emission Reductions from Solar PV

$$Emission\ Reductions = \sum_{n=1}^{30} (1 - Degradation)^{n-1} * Production * EF$$

Where,		Units
Emission Reductions	= GHG or criteria and toxic air pollutant emission reductions for useful life of solar PV system (30 years)[19]	$MTCO_2e$ or lbs
Degradation	= Annual rate of system degradation (0.5%)[19]	%/year
Production	= Annual electricity generation estimated using PVWatts Calculator	kWh/year
EF	= Emission factor for California grid electricity	$MTCO_2e$/ kWh or lbs/kWh

[19] The 30-year useful life was obtained from the National Renewable Energy Laboratory "Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics" fact sheet. www.nrel.gov/docs/fy13osti/56487.pdf The estimated rate of system degradation was obtained from the National Renewable Energy Laboratory Technical Report "Photovoltaic Degradation Rates – An Analytical Review." 2012. www.nrel.gov/docs/fy12osti/51664.pdf

C. New Bicycle Facility or Walkway

The emission reductions from new bicycle facilities or walkways are calculated as the emission reductions from displaced autos.

Equation 21: VMT Reductions from Bicycle Facility or Walkway

$$VMT\ Displaced = D * ADT * (A + C) * GFA * L$$

Where,			Units
VMT Displaced	=	Annual passenger VMT replaced by cycling or walking trips	miles/year
D	=	Default annual days of use of new facility (200 days)	days/year
ADT	=	Average two-way daily traffic on road parallel to facility	vehicle trips/day
A	=	Adjustment factor for active transportation (see Table 5)	unitless
C	=	Credit for Key Destinations near facility (see Table 6)	unitless
GFA	=	Growth factor adjustment (1.54 for new Class I bike paths and Class IV bikeways; 1.0 for new Class II bike lanes; 0.54 for Class II to IV conversion; 0.46 for new bicycle boulevards)	unitless
L	=	Average length of auto trip replaced (1.5 miles for cycling; 0.3 miles for walking)	miles

Table 5. Active Transportation Adjustment Factors

Average Daily Traffic (vehicle trips per day)	One-way Facility Length[20] (miles)	Adjustment Factor for Population > 250,000 or Non-university Town with Population < 250,000	Adjustment Factor University Town with Population < 250,000
1 to 12,000	≤ 1	0.0019	0.0104
	1.01 to 2	0.0029	0.0155
	> 2	0.0038	0.0207
12,001 to 24,000	≤ 1	0.0014	0.0073
	1.01 to 2	0.0020	0.0109
	> 2	0.0027	0.0145
24,001 to 30,000	≤ 1	0.0010	0.0052
	1.01 to 2	0.0014	0.0078
	> 2	0.0019	0.0104

[20] The length of bicycle facilities and walkways should be measured in one direction because the adjustment factor, based on length and two-way average daily traffic, accounts for trips in both directions. Crosswalks should not be included in the length of sidewalks since they are accounted for as traffic calming measures.

Table 6. Key Destination Credits

Number of Key Destinations	Credit Within ½ Mile of Facility	Credit Within ¼ Mile of Facility
0 to 2	0	0
3	0.0005	0.001
4 to 6	0.0010	0.002
≥ 7	0.0015	0.003

Equation 22: Auto Emission Reductions from Bicycle Facility or Walkway

$$Auto\ Emission\ Reductions = \left(\frac{VMT\ Displaced * EF_{Yr1} + VMT\ Displaced * EF_{YrF}}{2}\right) * UL * U^{-1}$$

Where,			Units
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for useful life of bicycle facility or walkway	$MTCO_2e$ or lbs
VMT Displaced	=	Annual passenger VMT replaced by cycling or walking trips, from Equation 21	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of useful life	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of useful life	g/mile
UL	=	Useful life of bicycle facility or walkway (20 years for Class I bike path or walkway; 15 years for Class II bike lane, Class IV separated bikeway, or bicycle boulevard)	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

D. New or Expanded Bike Share

The emission reductions from bike share components that result in an increase in bike trips are calculated as the emission reductions from displaced autos less the emissions from electric bicycles, if applicable.

Equation 23: VMT Reductions from Bike Share

$$VMT\ Displaced = \left(\frac{Trips_{Yr1} + Trips_{YrF}}{2}\right) * A * L$$

Where,			Units
VMT Displaced	=	Annual passenger VMT replaced by bike share trips	miles/year
$Trips_{Yr1}$	=	Total number of trips using bike share expected in first year	trips/year
$Trips_{YrF}$	=	Total number of trips using bike share expected in final year	trips/year
A	=	Adjustment factor to account for induced demand and recreational bike share use (0.5)	unitless
L	=	Average length of auto trip replaced (1.5 miles)	miles

Equation 24: Auto Emission Reductions from Bike Share

$$Auto\ Emission\ Reductions = \left(\frac{VMT\ Displaced * EF_{Yr1} + VMT\ Displaced * EF_{YrF}}{2}\right) * UL * U^{-1} - \left(\frac{Trips_{Yr1} + Trips_{YrF}}{2}\right) * L * EF_V * UL * U^{-1}$$

Where,			Units
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for useful life of bike share	$MTCO_2e$ or lbs
VMT Displaced	=	Annual passenger VMT replaced by bike share trips, from Equation 23	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of service	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of service	g/mile
EF_V	=	Emission factor for bike share collection and distribution vehicle	g/mile
$Trips_{Yr1}$	=	Total number of trips using bike share expected in first year	trips/year
$Trips_{YrF}$	=	Total number of trips using bike share expected in final year	trips/year
L	=	Average length of auto trip replaced (1.5 miles)	miles
UL	=	Quantification period for new bike share	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

Equations 25 and 26 apply to electric bike share only.

Equation 25: Emissions from Electric Bike Share

$$Electric\ Bicycle\ Emissions = \left(\frac{Trips_{Yr1} + Trips_{YrF}}{2}\right) * L * EF_B * UL * U^{-1}$$

Where,			Units
Electric Bicycle Emissions	=	Electric bicycle GHG or criteria and toxic air pollutant emissions for useful life of bike share	$MTCO_2e$ or lbs
$Trips_{Yr1}$	=	Total number of trips using bike share expected in first year	trips/year
$Trips_{YrF}$	=	Total number of trips using bike share expected in final year	trips/year
L	=	Average length of auto trip replaced (1.5 miles)	miles
EF_B	=	Emission factor for electric bicycles	g/mile
UL	=	Quantification period for bike share	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

Equation 26: Net Emission Reductions from Electric Bike Share

$$Net\ Emission\ Reductions = Auto\ Emission\ Reductions - Electric\ Bicycle\ Emissions$$

Where,			Units
Net Emission Reductions	=	GHG or criteria and toxic air pollutant emission reductions for useful life of electric bike share	$MTCO_2e$ or lbs
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for useful life of bike share, from Equation 24	$MTCO_2e$ or lbs
Electric Bicycle Emissions	=	Electric bicycle GHG or criteria and toxic air pollutant emissions for useful life of bike share, from Equation 25	$MTCO_2e$ or lbs

E. New or Expanded Bus, Cable Car, Rail, Streetcar, Shuttle, Trolley Bus, or Van Service

The emission reductions from new or expanded transit service are calculated as the emission reductions from displaced autos less the new emissions from transit vehicles.

Equation 27: VMT Reductions from New or Expanded Transit Service

$$VMT\ Displaced = R * A * L$$

Where,			Units
VMT Displaced	=	Annual passenger VMT replaced by transit trips	miles/year
R	=	Increase in annual transit ridership in first or last year of service	trips/year
A	=	Adjustment factor for transit dependency (default or user-defined; see Table 7)	unitless
L	=	Length of average auto trip replaced (default or user-defined; see Table 7)	miles

Table 7. Default Trip Lengths and Adjustment Factors by Mode

Mode	Statewide Average Trip Length (miles)[21]	Default Adjustment Factor
Bus rapid transit	6.56	0.542
Cable car	1.26	0.479
Commuter rail	25.69	0.867
Ferry	10.85	1.000
Heavy rail	11.48	0.794
Light rail	5.44	0.685
Local bus	3.77	0.561
Long-distance commuter bus	17.57	0.705
Microtransit shuttle or van	9.08	0.585
Streetcar	1.43	0.479
Trolley bus	1.48	0.479
Vanpool	42.28	0.879

[21] Federal Transit Administration. National Transit Database. 2017. www.transit.dot.gov/ntd. Caltrans calculated the statewide average trip lengths by mode as passenger miles traveled divided by unlinked passenger trips, using 2017 annual data.

Equation 28: Auto Emission Reductions from New or Expanded Transit Service

$$Auto\ Emission\ Reductions = \frac{(VMT\ Displaced_{Yr1} * EF_{Yr1}) + (VMT\ Displaced_{YrF} * EF_{YrF})}{2} * UL * U^{-1}$$

Where,			Units
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded service	$MTCO_2e$ or lbs
$VMT\ Displaced_{Yr1}$	=	Annual passenger VMT replaced by transit trips in first year of service, from Equation 27	miles/year
$VMT\ Displaced_{YrF}$	=	Annual passenger VMT replaced by transit trips in final year of service, from Equation 27	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of service	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of service	g/mile
UL	=	Quantification period for transit service	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

The quantification period for a transit component is the number of years for which there are enforceable committed funds to operate the transit service using the AHSC-funded vehicle(s), capital improvement(s), operations, and/or fare reduction, not to exceed 50 years. For transit operations or fare reductions without vehicle purchases or capital improvements, the quantification period is the number of years that the new or expanded transit service or fare reduction will be provided with AHSC Round 6 funding, up to five years.

Equation 29 is applicable only to rail vehicles, when information on the additional fuel consumed rather than the VMT to operate new or expanded service is available.

Equation 29: Rail Vehicle VMT from Fuel Consumption

$$Rail\ Vehicle\ VMT\ =\ Fuel\ Consumed * Consumption\ Rate^{-1} * U^{-1}$$

Where,			Units
Rail Vehicle VMT	=	Annual VMT of rail vehicles to operate new or expanded service	miles/year
Fuel Consumed	=	Annual fuel consumed by rail vehicles to operate new or expanded service	units of fuel/year
Consumption Rate	=	Statewide average fuel consumption rate for locomotives	gallons of diesel/mile
U	=	Unit conversion factor for diesel gallon equivalent	units of fuel/diesel gallon equivalent

Equation 30: Transit Vehicle Emissions

$$Transit\ Vehicle\ Emissions\ =\ Transit\ VMT * EF_{YrM} * UL * U^{-1}$$

Where,			Units
Transit Vehicle Emissions	=	Transit vehicle GHG or criteria and toxic air pollutant emissions for quantification period of new or expanded service	$MTCO_2e$ or lbs
Transit VMT	=	Annual VMT of transit vehicles to operate new or expanded service	miles/year
EF_{YrM}	=	Transit vehicle emission factor for middle year of service	g/mile
UL	=	Quantification period for transit service	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

Equation 31: Net Emission Reductions from New or Expanded Transit Service

$$Net\ Emission\ Reductions = Auto\ Emission\ Reductions - Transit\ Vehicle\ Emissions$$

Where,			Units
Net Emission Reductions	=	GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded transit service	$MTCO_2e$ or lbs
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded service, from Equation 28	$MTCO_2e$ or lbs
Transit Vehicle Emissions	=	Transit vehicle GHG or criteria and toxic air pollutant emissions for quantification period of new or expanded service, from Equation 30	$MTCO_2e$ or lbs

F. New or Expanded Ferry Service

The emission reductions from new or expanded ferry service are calculated as the emission reductions from displaced autos less the new emissions from the ferry.

Equation 32: VMT Reductions from New or Expanded Ferry Service

$$VMT\ Displaced = D * R * A * L$$

Where,			Units
VMT Displaced	=	Annual passenger VMT replaced by ferry trips	miles/year
D	=	Annual days of operation of ferry service	days/year
R	=	Increase in daily ferry ridership in first or last year of service	trips/day
A	=	Adjustment factor for transit dependency (default or user-defined; see Table 7)	unitless
L	=	Length of average auto trip replaced (default or user-defined; see Table 7)	miles

Equation 33: Auto Emission Reductions from New or Expanded Ferry Service

$$Auto\ Emission\ Reductions = \frac{(VMT\ Displaced_{Yr1} * EF_{Yr1}) + (VMT\ Displaced_{YrF} * EF_{YrF})}{2} * UL * U^{-1}$$

Where,			Units
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded service	$MTCO_2e$ or lbs
$VMT\ Displaced_{Yr1}$	=	Annual passenger VMT replaced by ferry trips in first year of service, from Equation 32	miles/year
$VMT\ Displaced_{YrF}$	=	Annual passenger VMT replaced by ferry trips in final year of service, from Equation 32	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of service	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of service	g/mile
UL	=	Quantification period for ferry service	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

Equation 34: Ferry Emissions

$$Ferry\ Emissions = Fuel\ Consumption * EF * UL * U^{-1}$$

Where,			Units
Ferry Emissions	=	Ferry GHG or criteria and toxic air pollutant emissions for quantification period of new or expanded service	$MTCO_2e$ or lbs
Fuel Consumption	=	Annual quantity of fuel consumed by ferry to operate new or expanded service	gal, scf, kWh, or kg
EF	=	Fuel-specific carbon intensity emission factor for ferry	g/unit of fuel
UL	=	Quantification period for ferry service	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

Equation 35: Net Emission Reductions from New or Expanded Ferry Service

$$Net\ Emission\ Reductions = Auto\ Emission\ Reductions - Ferry\ Emissions$$

Where,			Units
Net Emission Reductions	=	GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded ferry service	$MTCO_2e$ or lbs
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded service, from Equation 33	$MTCO_2e$ or lbs
Ferry Emissions	=	Ferry GHG or criteria and toxic air pollutant emissions for quantification period of new or expanded service, from Equation 34	$MTCO_2e$ or lbs

G. Capital Improvements and Fare Reductions

The emission reductions from capital improvements and fare reductions that result in mode shift to transit are calculated as the emission reductions from displaced autos.

Equation 36: VMT Reductions from Capital Improvements or Fare Reductions

$$VMT\ Displaced = D * R * A * L$$

Where,			Units
VMT Displaced	=	Annual passenger VMT replaced by transit trips	miles/year
D	=	Annual days of operation of transit service utilizing capital improvement or when fare reduction is provided	days/year
R	=	Increase in daily transit ridership in first or last year of service	trips/day
A	=	Adjustment factor for transit dependency (default or user-defined; see Table 7)	unitless
L	=	Length of average auto trip reduced (default or user-defined; see Table 7)	miles

Equation 37: Auto Emission Reductions from Capital Improvements or Fare Reductions

$$Auto\ Emission\ Reductions = \left(\frac{VMT\ Displaced_{Yr1} * EF_{Yr1} + VMT\ Displaced_{YrF} * EF_{YrF}}{2}\right) * UL * U^{-1}$$

Where,			Units
Auto Emission Reductions	=	Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of capital improvement or fare reduction	$MTCO_2e$ or lbs
VMT Displaced	=	Annual passenger VMT replaced by transit trips, from Equation 36	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of service	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of service	g/mile
UL	=	Quantification period for transit utilizing capital improvement or fare reduction	years
U	=	Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

Section C. References

The following references were used in the development of this Quantification Methodology and the AHSC Benefits Calculator Tool.

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