

**California Air Resources Board**

## **Quantification Methodology**

**Strategic Growth Council  
Affordable Housing and Sustainable Communities Program**

**California Climate Investments**



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**List of Acronyms and Abbreviations**

<b>Acronym</b>	<b>Term</b>
AHSC	Affordable Housing and Sustainable Communities
CARB	California Air Resources Board
CMAQ	Congestion Mitigation and Air Quality
Diesel PM <sub>10</sub>	diesel particulate matter with a diameter less than 10 micrometers
DC	direct current
g	grams
gal	gallons
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
ICP	Integrated Connectivity Project Area
kg	kilograms
kWh	kilowatt hours
lbs	pounds
MTCO <sub>2e</sub>	metric tons of carbon dioxide equivalent
NO <sub>x</sub>	nitrous oxide
PM <sub>2.5</sub>	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/ccr-expenditurerecords](http://www.arb.ca.gov/ccr-expenditurerecords).

For the SGC AHSC Program, CARB and SGC 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/ccr-resources](http://www.arb.ca.gov/ccr-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<sub>x</sub> emission reductions (lbs);
- Local and remote PM<sub>2.5</sub> emission reductions (lbs);
- Local diesel PM<sub>10</sub> 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<sup>1</sup>, solicitation materials, and agreements to ensure they meet AHSC requirements. All CARB co-benefit assessment methodologies are available at: [www.arb.ca.gov/ci-cobenefits](http://www.arb.ca.gov/ci-cobenefits).

## Methodology Development

CARB and SGC developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.<sup>2</sup> 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 August 2019. 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 reduction estimates for transit and connectivity project features.<sup>3</sup> The CMAQ

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<sup>1</sup> Strategic Growth Council. <http://sgc.ca.gov/programs/ahsc/resources/guidelines.html>

<sup>2</sup> California Air Resources Board. [www.arb.ca.gov/ci-fundingguidelines](http://www.arb.ca.gov/ci-fundingguidelines)

<sup>3</sup> 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*

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](http://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,<sup>4</sup> metropolitan planning organizations,<sup>5</sup> the Institute of Transportation Engineers Trip Generation Manual<sup>6</sup> and Parking Generation Manual,<sup>7</sup> and the California Air Pollution Control Officers Association “Quantifying Greenhouse Gas Mitigation Measures” report<sup>8</sup> and California Emissions Estimator Model®.<sup>9</sup> 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](http://www.arb.ca.gov/cci-cobenefits).

The AHSC Quantification Methodology and AHSC Benefits Calculator Tool are applicable only to AHSC project types and should not be used to estimate GHG

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*Projects and Congestion Mitigation and Air Quality Improvement Projects.* May 2005. [www.arb.ca.gov/planning/tsaq/eval/eval.htm](http://www.arb.ca.gov/planning/tsaq/eval/eval.htm).

<sup>4</sup> California Department of Transportation. *California Statewide Travel Demand Model.* 2016. <https://dot.ca.gov/programs/transportation-planning/multi-modal-system-planning/statewide-modeling>

<sup>5</sup> 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.

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

<sup>7</sup> Institute of Transportation Engineers. *Parking Generation Manual, 4<sup>th</sup> Edition.* 2010. <https://www.ite.org/technical-resources/topics/trip-and-parking-generation/>

<sup>8</sup> 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](http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf)

<sup>9</sup> California Air Pollution Control Officers Association. *California Emissions Estimator Model, version 2016.3.2.* 2017. [www.caleemod.com](http://www.caleemod.com).

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: <http://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: <http://www.arb.ca.gov/cc-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: <http://www.arb.ca.gov/cc-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<sup>10</sup> to enhance the analysis and provide additional clarity, including the following additions:

- Equations to estimate avoided VMT from affordable housing developments;
- Home-based trip length information from metropolitan planning organizations and the California Statewide Travel Demand Model;

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<sup>10</sup> California Air Resources Board. November 2018. <https://ww2.arb.ca.gov/our-work/programs/california-climate-investments/cc-archived-quantification-materials>

- Trip generation rates from 10<sup>th</sup> Edition Institute of Transportation Engineers Trip Generation Manual, including “Senior Adult Housing (Attached)” trip rates for age-restricted housing rather than “Retirement Community” trip rates;
- Compound degradation for solar PV electricity generation estimates;
- Calculations of criteria and toxic air pollutant emission reductions from transit and active transportation components past 2050;
- Passenger auto and transit vehicle emission factors derived from EMFAC2017;
- Updated default trip lengths for transit and active transportation components;
- Equations to estimate GHG emission reductions and co-benefits from electric bike share;
- Updated costs for energy, fuel, and transportation;
- Descriptions of additional data sources used; and
- An expanded project example and additional guidance to clarify frequently asked questions.



## 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.<sup>11</sup> 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 (Class I bike path, Class II bike lane, or Class IV separated bikeway)
	New walkway
	New bike share equipment <sup>12</sup>
	New or expanded transit service (bus, cable car, ferry, heavy rail, light rail, streetcar, shuttle, trolley bus, or vanpool)
	Capital improvement that encourages mode shift
Program	Transit passes for residents
	New bike share operations <sup>12</sup>

<sup>11</sup> Strategic Growth Council. <http://sgc.ca.gov/programs/ahsc/resources/guidelines.html>

<sup>12</sup> 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.

## 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**

<b>Project Component</b>	<b>Emission Reductions Estimated</b>
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, if applicable)
New or expanded transit service	Emissions from displaced autos less emissions from new service vehicle
Capital improvements	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.<sup>13</sup>

### Equation 1: Average Daily Trips per Dwelling Unit

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

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

<sup>13</sup> 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*.

<http://www.aqmd.gov/caleemod/user's-guide>

Trip rates are derived from the *Trip Generation Manual, 10<sup>th</sup> Edition*.

<https://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.

<https://dot.ca.gov/programs/transportation-planning/multi-modal-system-planning/statewide-modeling>

**Equation 2: Primary Trip Length***Primary Trip Length*

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

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

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

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

**Equation 4: Annual Unmitigated VMT***Annual Unmitigated VMT*

$$= \text{Average Daily Trips} * \text{Overall Trip Length} * \text{Total Units} * 365 \text{ days}$$

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

Equations 5 through 17 are used to calculate the expected percent reductions in passenger VMT resulting from the characteristics of the affordable housing development.<sup>14</sup>

**Equation 5: VMT Reductions from Increased Density**

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

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

<sup>14</sup> 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](http://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) <sup>15</sup>
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,		<u>Units</u>
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,		<u>Units</u>
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

<sup>15</sup> Strategic Growth Council. <http://sgc.ca.gov/programs/ahsc/resources/guidelines.html>

**Equation 8: VMT Reductions from Increased Destination Accessibility**

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

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

**Equation 9: VMT Reductions from Integration of Affordable Housing**

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

Where,		
Affordability VMT Reductions	= VMT reductions associated with integration of affordable dwelling units into housing development, capped at 4%	<u>Units</u> %
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

**Equation 10: Total VMT Reductions from Land Use Measures**

$$\begin{aligned} \text{Land Use VMT Reductions} \\ = 1 - (1 - \text{Density VMT Reductions}) * (1 - \text{Diversity VMT Reductions}) \\ * (1 - \text{Accessibility VMT Reductions}) \\ * (1 - \text{Affordability VMT Reductions}) \end{aligned}$$

Where,		
Land Use VMT Reductions	= VMT reductions associated with all land use measures, capped according to Project Area Type (see Table 4)	<u>Units</u> %
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<sup>16</sup>**

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%

**Equation 11: VMT Reductions from Limited Parking Supply***Parking Supply VMT Reductions*

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

Where, Parking Supply VMT Reductions	= VMT reductions associated with limited residential parking supply, capped at 12.5%	<u>Units</u> %
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**

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

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

<sup>16</sup> 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](http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf)



### Equation 13: VMT Reductions from Increased On-street Parking Price

$$\text{Street Parking VMT Reductions} = \text{Street Cost} * 0.11$$

Where,		<u>Units</u>
Street Parking VMT Reductions	= VMT reductions associated with increased price of on-street parking, capped at 5.5%	%
Street Cost	= Percent increase in on-street parking price above baseline within ½ mile of affordable housing development	%

### Equation 14: Total VMT Reductions from Parking Measures

$$\text{Parking VMT Reductions}$$

$$= 1 - (1 - \text{Parking Supply VMT Reductions}) \\ * (1 - \text{Unbundled Parking VMT Reductions}) \\ * (1 - \text{Street Parking VMT Reductions})$$

Where,		<u>Units</u>
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	%
Street Parking VMT Reductions	= VMT reductions associated with increased price of on-street parking, capped at 5.5%, from Equation 13	%

### Equation 15: VMT Reductions from Traffic Calming Measures

$$\text{Traffic Calming VMT Reductions} = 1\%$$

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

**Equation 16: VMT Reductions from Residential Transit Subsidy**

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

Where, Subsidy VMT Reductions	= VMT reductions associated with transit passes for residents, capped at 20%	<u>Units</u> %
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 17: Total VMT Reductions**

*Total VMT Reductions*

$$= \text{Land Use VMT Reductions} + \text{Parking VMT Reductions} + \text{Traffic Calming VMT Reductions} + \text{Subsidy VMT Reductions}$$

Where, Total VMT Reductions	= VMT reductions associated with all mitigation measures, capped according to Project Area Type (see Table 3)	<u>Units</u> %
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 14	%
Traffic Calming VMT Reductions	= VMT reductions associated with traffic calming measures within ½ mile of affordable housing development, from Equation 15	%
Subsidy VMT Reductions	= VMT reductions associated with transit passes for residents, capped at 20%, from Equation 16	%

Equations 18 and 19 are used to apply the expected percent reductions in VMT to estimate avoided VMT from the affordable housing development.

#### Equation 18: Annual Avoided VMT

$$\text{Annual Avoided VMT} = \text{Annual Unmitigated VMT} * \text{Total VMT Reductions}$$

Where,		<u>Units</u>
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 17	%

#### Equation 19: Total Avoided VMT

$$\text{Total Avoided VMT} = \text{Annual Avoided VMT} * 30 \text{ years}$$

Where,		<u>Units</u>
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 20: Auto Emission Reductions from Affordable Housing Development and Residential Transit Subsidies

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

Where,		<u>Units</u>
Auto Emission Reductions	= Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of affordable housing development (30 years)	MTCO <sub>2</sub> e or lbs
Annual Avoided VMT	= Annual reductions in baseline residential VMT, from Equation 18	miles/year
EF <sub>Yr1</sub>	= County-specific auto vehicle emission factor for first year of project life	g/mile
EF <sub>YrF</sub>	= 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.<sup>17</sup>

### Equation 21: Emission Reductions from Solar PV

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

<i>Where,</i>		<u>Units</u>
<i>Emission Reductions</i>	= GHG or criteria and toxic air pollutant emission reductions for useful life of solar PV system (30 years)	MTCO <sub>2e</sub> or lbs
<i>Degradation</i>	= Annual rate of system degradation (0.5%)	%/year
<i>Production</i>	= Annual electricity generation estimated using PVWatts Calculator	kWh/year
<i>EF</i>	= Emission factor for California grid electricity	MTCO <sub>2e</sub> /kWh or lbs/kWh

<sup>17</sup> 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](http://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](http://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 22: VMT Reductions from Bicycle Facility or Walkway

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

Where,		Units
<i>VMT Displaced</i>	= Annual passenger VMT replaced by cycling or walking trips	miles/year
<i>D</i>	= Default annual days of use of new facility (200 days)	days/year
<i>ADT</i>	= Average two-way daily traffic on road parallel to facility	vehicle trips/day
<i>A</i>	= Adjustment factor for active transportation (see Table 5)	unitless
<i>C</i>	= Credit for Key Destinations near facility (see Table 6)	unitless
<i>L</i>	= 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 <sup>18</sup> (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

<sup>18</sup> The length of bicycle facilities and walkways should be measured in one direction because average daily traffic accounts for two-way traffic volume. 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 23: Auto Emission Reductions from Bicycle Facility or Walkway**

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

<i>Where,</i>		
<i>Auto Emission Reductions</i>	= Auto GHG or criteria and toxic air pollutant emission reductions for useful life of bicycle facility or walkway	<u>Units</u> MTCO <sub>2e</sub> or lbs
<i>VMT Displaced</i>	= Annual passenger VMT replaced by cycling or walking trips, from Equation 22	miles/year
<i>EF<sub>Yr1</sub></i>	= County-specific auto vehicle emission factor for first year of useful life	g/mile
<i>EF<sub>YrF</sub></i>	= County-specific auto vehicle emission factor for final year of useful life	g/mile
<i>UL</i>	= Useful life of bicycle facility or walkway (20 years for Class I bike path or walkway; 15 years for Class II bike lane or Class IV separated bikeway)	years
<i>U</i>	= 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 24: VMT Reductions from Bike Share

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

<i>Where,</i>		<u>Units</u>
<i>VMT Displaced</i>	= Annual passenger VMT replaced by bike share trips	miles/year
<i>T</i>	= Total number of trips using bike share expected in first year of service	trips/year
<i>A</i>	= Adjustment factor to account for induced demand and recreational bike share use (0.5)	unitless
<i>L</i>	= Average length of auto trip replaced (1.5 miles)	miles

### Equation 25: Auto Emission Reductions from Bike Share

*Auto Emission Reductions*

$$= \left( \frac{VMT\ Displaced * EF_{Yr1} + VMT\ Displaced * EF_{YrF}}{2} \right) * 10\ years * U^{-1}$$

<i>Where,</i>		<u>Units</u>
<i>Auto Emission Reductions</i>	= Auto GHG or criteria and toxic air pollutant emission reductions for useful life of bike share (10 years)	MTCO <sub>2</sub> e or lbs
<i>VMT Displaced</i>	= Annual passenger VMT replaced by bike share trips, from Equation 24	miles/year
<i>EF<sub>Yr1</sub></i>	= County-specific auto vehicle emission factor for first year of service	g/mile
<i>EF<sub>YrF</sub></i>	= County-specific auto vehicle emission factor for final year of service	g/mile
<i>U</i>	= Unit conversion factor (1,000,000 for grams to metric tons; 453.59 for grams to pounds)	g/MT or g/lb

Equations 26 and 27 apply to electric bike share only.

### Equation 26: Emissions from Electric Bike Share

$$\text{Electric Bicycle Emissions} = T * L * EC * EF * 10 \text{ years}$$

Where,		<u>Units</u>
Electric Bicycle Emissions	= Electric bicycle GHG or criteria and toxic air pollutant emissions for useful life of bike share (10 years)	MTCO <sub>2e</sub> or lbs
T	= Total number of trips using bike share expected in first year of service	trips
L	= Average length of auto trip replaced (1.5 miles)	miles
EC	= Energy consumption per mile for electric bicycles	kWh/mile
EF	= Emission factor for California grid electricity	MTCO <sub>2e</sub> /kWh or lbs/kWh

### Equation 27: Net Emission Reductions from Electric Bike Share

$$\text{Net Emission Reductions} = \text{Auto Emission Reductions} - \text{Electric Bicycle Emissions}$$

Where,		<u>Units</u>
Net Emission Reductions	= GHG or criteria and toxic air pollutant emission reductions for useful life of electric bike share (10 years)	MTCO <sub>2e</sub> or lbs
Auto Emission Reductions	= Auto GHG or criteria and toxic air pollutant emission reductions for useful life of bike share, from Equation 25	MTCO <sub>2e</sub> or lbs
Electric Bicycle Emissions	= Electric bicycle GHG or criteria and toxic air pollutant emissions for useful life of bike share, from Equation 26	MTCO <sub>2e</sub> or lbs



## E. New or Expanded Bus, Cable Car, Rail, Streetcar, Shuttle, Trolley Bus, or Vanpool 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 28: VMT Reductions from New or Expanded Transit Service

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

Where,		<u>Units</u>
<i>VMT Displaced</i>	= Annual passenger VMT replaced by transit trips	miles/year
<i>D</i>	= Annual days of operation of transit service	days/year
<i>R</i>	= Increase in daily transit ridership in first or last year of service	trips/day
<i>A</i>	= Adjustment factor for transit dependency (default or user-defined; see Table 7)	unitless
<i>L</i>	= 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) <sup>19</sup>	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
Shuttle	9.08	0.585
Streetcar	1.43	0.479
Trolley bus	1.48	0.479
Vanpool	42.28	0.879

<sup>19</sup> Federal Transit Administration. National Transit Database. 2017. <https://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 29: 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,

<i>Auto Emission Reductions</i>	= Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded service	<u>Units</u> MTCO <sub>2e</sub> or lbs
<i>VMT Displaced<sub>Yr1</sub></i>	= Annual passenger VMT replaced by transit trips in first year of service, from Equation 28	miles/year
<i>VMT Displaced<sub>YrF</sub></i>	= Annual passenger VMT replaced by transit trips in final year of service, from Equation 28	miles/year
<i>EF<sub>Yr1</sub></i>	= County-specific auto vehicle emission factor for first year of service	g/mile
<i>EF<sub>YrF</sub></i>	= County-specific auto vehicle emission factor for final year of service	g/mile
<i>UL</i>	= Quantification period for transit service, not to exceed maximum useful life per capital type (see Table 8)	years
<i>U</i>	= 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 new or expanded service. The quantification period may not exceed the maximum useful life defined per capital type by the Federal Transit Administration guidelines.<sup>20</sup>

**Table 8. Maximum Useful Life by Capital Type**

Capital Type	Maximum Useful Life (years)
Bus	12
Ferry	25
Rail vehicle	25
Shuttle	10
Structure	40
Van	4

<sup>20</sup> Federal Transit Administration. Circular FTA C 5010.1E. July 2018.  
[www.transit.dot.gov/regulations-and-guidance/fta-circulars/award-management-requirements-circular-50101e](http://www.transit.dot.gov/regulations-and-guidance/fta-circulars/award-management-requirements-circular-50101e)

**Equation 30: Transit Vehicle Emissions**

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

Where,		<u>Units</u>
Transit Vehicle Emissions	= Transit vehicle GHG or criteria and toxic air pollutant emissions for quantification period of new or expanded service	MTCO <sub>2e</sub> or lbs
Transit VMT	= Annual VMT of transit vehicles to operate new or expanded service	miles/year
EF <sub>YrM</sub>	= Transit vehicle emission factor for middle year of service	g/mile
UL	= Quantification period for transit service, not to exceed maximum useful life per capital type (see Table 8)	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**

$$\text{Net Emission Reductions} = \text{Auto Emission Reductions} - \text{Transit Vehicle Emissions}$$

Where,		<u>Units</u>
Net Emission Reductions	= GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded transit service	MTCO <sub>2e</sub> 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 29	MTCO <sub>2e</sub> 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 <sub>2e</sub> 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

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

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

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

<i>Where,</i>		<u>Units</u>
<i>Auto Emission Reductions</i>	= Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded service	MTCO <sub>2e</sub> or lbs
<i>VMT Displaced<sub>Yr1</sub></i>	= Annual passenger VMT replaced by ferry trips in first year of service, from Equation 32	miles/year
<i>VMT Displaced<sub>YrF</sub></i>	= Annual passenger VMT replaced by ferry trips in final year of service, from Equation 32	miles/year
<i>EF<sub>Yr1</sub></i>	= County-specific auto vehicle emission factor for first year of service	g/mile
<i>EF<sub>YrF</sub></i>	= County-specific auto vehicle emission factor for final year of service	g/mile
<i>UL</i>	= Quantification period for ferry service, not to exceed 25 years (see Table 8)	years

**Equation 34: Ferry Emissions**

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

<i>Where,</i>		<u>Units</u>
<i>Ferry Emissions</i>	= Ferry GHG or criteria and toxic air pollutant emissions for quantification period of new or expanded service	MTCO <sub>2</sub> e or lbs
<i>Fuel Consumption</i>	= Annual quantity of fuel consumed by ferry to operate new or expanded service	gal, scf, kWh, or kg
<i>EF</i>	= Fuel-specific carbon intensity emission factor for ferry	g/unit of fuel
<i>UL</i>	= Quantification period for ferry service, not to exceed 25 years (see Table 8)	years
<i>U</i>	= 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**

$$\text{Net Emission Reductions} = \text{Auto Emission Reductions} - \text{Ferry Emissions}$$

<i>Where,</i>		<u>Units</u>
<i>Net Emission Reductions</i>	= GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded ferry service	MTCO <sub>2</sub> e or lbs
<i>Auto Emission Reductions</i>	= Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of new or expanded service, from Equation 33	MTCO <sub>2</sub> e or lbs
<i>Ferry Emissions</i>	= Ferry GHG or criteria and toxic air pollutant emissions for quantification period of new or expanded service, from Equation 34	MTCO <sub>2</sub> e or lbs

## G. Capital Improvements

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

### Equation 36: VMT Reductions from Capital Improvements

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

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

### Equation 37: Auto Emission Reductions from Capital Improvements

*Auto Emission Reductions*

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

Where,		<u>Units</u>
<i>Auto Emission Reductions</i>	= Auto GHG or criteria and toxic air pollutant emission reductions for quantification period of capital improvement	MTCO <sub>2</sub> e or lbs
<i>VMT Displaced</i>	= Annual passenger VMT replaced by transit trips, from Equation 36	miles/year
<i>EF<sub>Yr1</sub></i>	= County-specific auto vehicle emission factor for first year of service	g/mile
<i>EF<sub>YrF</sub></i>	= County-specific auto vehicle emission factor for final year of service	g/mile
<i>UL</i>	= Quantification period for transit utilizing capital improvement service, not to exceed 40 years (see Table 8)	years
<i>U</i>	= 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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